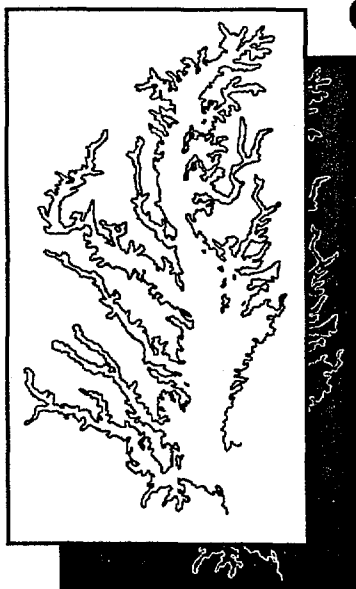


Sediment and Nutrient Contributions of Selected Eroding Banks of the Chesapeake Bay Estuarine System



*by Nancy A. Ibison, Chris W. Frye, Jack E. Frye,
Carlton Lee Hill and Ned H. Burger*

January 1990



**Department of Conservation and Recreation
Division of Soil and Water Conservation
Shoreline Programs Bureau
Gloucester Point, VA**

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EXECUTIVE SUMMARY

In the 1987 Chesapeake Bay Agreement, the participants targeted nitrogen and phosphorus contributions to the mainstem of the Chesapeake Bay for a 40% reduction by the year 2000. To meet this goal, all possible sources of point and nonpoint source nutrient inputs need to be examined. Although research has been or is being conducted on agricultural, atmospheric and groundwater contributions of nonpoint source pollution, the role of sediment and nutrients from tidal shoreline erosion has not been addressed.

To examine the role of sediment and nutrients from tidal shoreline erosion, 14 eroding banks were selected on the Chesapeake Bay and the Potomac, Rappahannock, York and James Rivers. Site selection was based on historical erosion rates of greater than 2.0 feet per year and erosion volumes of greater than 1.0 cubic yard per foot per year. Most sites were also located within 1400 feet of living marine resources. Soil samples were collected and analyzed for grain size, total nitrogen, total phosphorus and inorganic phosphorus.

Results of grain size analysis indicated a large difference between shore sediments and fastland sediments, attributed to transport of fine grained fractions away from the foreshore. Fastland nitrogen and phosphorus concentrations were not found to differ significantly among the sites. Nitrogen concentrations at the sites showed a more consistent relationship with grain size and bank height than phosphorus concentrations. Nutrient loading rates differed among the sites due to the influence of bank height and erosion rate on the calculated volume rates.

A quantitative comparison of upland erosion with shoreline erosion indicates that the large volumes of material lost by shoreline erosion processes result in large nutrient inputs directly into receiving waters. An estimated 1.37 million pounds per year of nitrogen is entering the Bay

ecosystem through shoreline erosion. This quantity of nitrogen is equivalent to 5.2% of the controllable nonpoint source nitrogen load. Additionally, an estimated 0.94 million pounds per year of phosphorus, equivalent to 23.6% of the controllable nonpoint source phosphorus load, is entering the Bay ecosystem. Further research is needed to better determine the total magnitude of nutrient inputs from shoreline erosion and to determine the influence of the shoreline erosion contribution on the 40% nutrient reduction goal.

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I. INTRODUCTION

Although the Chesapeake Bay estuary has been threatened and exploited by man's activities, extensive efforts are underway to reverse the trend toward decline. Virginia, Maryland, Pennsylvania and the District of Columbia have made a joint commitment to improve conditions in the Bay. Water quality was one of the key priorities targeted in the 1987 Chesapeake Bay Agreement. According to the Agreement, the improvement and maintenance of water quality are the most critical issues for the restoration of the Chesapeake Bay. To address the water quality issues, a joint commitment was made to reduce the nitrogen and phosphorus entering the mainstem of the Chesapeake Bay by 40% by the year 2000. The reduction is to be achieved by control of both point and non-point source pollution. Point source pollution results from the discharge of sewage treatment plants, industries or other operations where effluent is discharged at a specific location. Nonpoint source pollution is diffuse and may result from human activities or natural causes. Nonpoint source pollution includes surface water runoff from rural and urban land, groundwater and atmospheric inputs and the contribution from shoreline erosion. It is the latter source which we will address in this report.

In the Commonwealth of Virginia, the Division of Soil and Water Conservation of the Department of Conservation and Recreation is the lead agency for nonpoint source pollution control. The Division addresses the 40% nutrient reduction goal through several programs. The Division administers the Chesapeake Bay Agricultural BMP Cost-Share program which seeks to reduce the agricultural nonpoint source inputs through the use of best management practices (BMPs) on the land. The Nutrient Management program also provides advice to farmers on fertilizer application, crop planning and livestock manure control. Urban nonpoint source pollution is addressed through the Erosion and Sediment Control program and the new Stormwater Management program. In order to achieve the 40% nutrient reduction goal, all possible sources of non-point source nitrogen and phosphorus need to be examined. However, the contribution of sediment and nutrients from tidal shoreline erosion is not known. Therefore, the present study was undertaken by the Shoreline

Programs Bureau of the Division to identify and quantify the importance of this source.

Tidal shoreline erosion contributes to the nonpoint source pollution of the Chesapeake Bay through the introduction of sediment and nutrients into the system. Shoreline erosion provides a major source of sand for the estuarine beach and bar system. However, the deposition of sediment on sessile aquatic organisms, such as oysters, clams or submerged aquatic vegetation, may also occur. The finer sediment fractions become incorporated into the suspended sediment load, increasing the turbidity of the estuary. Moreover, nutrients adsorbed to clay particles increase the eutrophication problems of the Bay.

In an ecosystem, the health of the whole community depends on the health of the primary producers. Excessive nutrient enrichment and increased turbidity from suspended solids are thought to be major factors in the decline of submerged aquatic vegetation in the Chesapeake Bay. The increased nutrient levels also cause algal blooms and subsequent declines in dissolved oxygen levels.

Sediment budgets, shore erosion rates and eroded sediment volumes for selected portions of the Bay and the entire system have been calculated in previous studies. This information is useful in evaluating the role of shoreline erosion in nonpoint source pollution. Only limited work has been done on the grain size of fastland soils as a sediment source to the Bay. (The term fastland refers to the high ground along the shore, not the marshland.) Similarly, considerable nonpoint source nutrient work has focused on soluble nitrogen and phosphorus concentrations in runoff. Studies of atmospheric nutrient inputs have been conducted and studies of nutrient inputs from groundwater have also been initiated. However, the contribution of nitrogen and phosphorus from the introduction of sediment into the Bay via shoreline erosion has not been examined.

Because of the importance of nonpoint source pollution to the 40% nutrient reduction commitment, this study provides a preliminary estimate of the contributions associated with shoreline erosion. Specifically, we will examine the following objectives:

1. To select study sites from shoreline areas in Virginia's portion of the Chesapeake Bay estuary with the highest erosion rates and volumes that are located within 1400 feet of living marine resources.
2. To calculate nutrient loading rates for the selected sites based on measured nutrient concentrations, erosion rates and erosion volumes.
3. To determine if significant differences exist in the nitrogen and phosphorus concentrations among the sites sampled.
4. To investigate the differences in nutrient concentration and grain size distribution between fastland and shore sediments.

The findings of this study will help clarify the role of shoreline erosion to nonpoint source nutrient pollution.

Background Literature

Nutrient Studies and Budgets

Because of the need to quantify the role of agricultural runoff to nonpoint source pollution, a number of studies have examined agricultural runoff or studied the effectiveness of Best Management Practices (BMPs) in controlling surface water concentrations of nitrogen, phosphorus and sediment. The studies that examined runoff have little relevance to this project because residual nutrient concentrations in the soils were not measured. Mostaghimi et al. (1989) measured the nitrate nitrogen remaining in the soil profile above the water table at Nomini Creek watershed in Westmoreland County, Virginia. Soil extractable nitrate nitrogen was measured in mg/l and converted to kg/ha using the bulk density of the soil.

The U.S. Environmental Protection Agency report Chesapeake Bay Program Technical Studies: A Synthesis (1982) presented an estimated nitrogen and phosphorus "budget" for the Bay that partitioned the nutrient load to the Bay among the following sources: atmospheric inputs,

riverine inputs, point source contributions, bottom sources and ocean sources. The report excluded nonpoint source pollution inputs from below the fall line due to the lack of data. Nutrient loads due to the sediment contributions from shoreline erosion, the ocean and planktonic skeletal material were not estimated. The accuracy of the proposed budget is limited by lack of data from these nutrient components.

Correll (1987) also partitioned the nitrogen and phosphorus inputs to the Bay. He attributed 65% of the nitrogen and 22% of the phosphorus to "land discharge" (nonpoint source pollution). Point sources were estimated to contribute 25% of the nitrogen load and 73% of the phosphorus load. Atmospheric contributions of nitrogen and phosphorus were 10% and 5%, respectively. Correll concluded that the largest land discharge nitrogen component is nitrate nitrogen, which is mainly released to groundwater. The remaining nitrogen would primarily be organic nitrogen, which is released in runoff. The phosphorus in the land discharge component would primarily be adsorbed to soil particles and released in runoff.

Sediment Studies and Budgets

Annual shoreline erosion rates and volumes were calculated for the Virginia portion of the Chesapeake Bay and its tributaries by Byrne and Anderson (1977), the U.S. Army Corps of Engineers (1986) and the VIMS Shoreline Inventory Computer Database (unpublished). The information provides an insight into the quantity of sediment historically lost to erosion in a given area. The current project used the U.S. Army Corps of Engineers (1986) report and the VIMS Shoreline Inventory Computer Database to identify reaches with critically eroding shorelines adjacent to living marine resources and to select sampling sites in reaches where shoreline erosion might adversely impact these resources.

Biggs (1970) developed a suspended sediment (silt and clay) budget for the Chesapeake Bay north of the Potomac River. He examined the suspended sediment contributions from shoreline erosion, biological sources and fluvial inputs. He sampled fastland banks in 40 locations for an area he termed the "middle bay" which extended from the Chester River south to just above the Potomac River. Thickness of the strata as well as the amount of silt and clay was measured. A weighted average percent

of silt and clay for a given bank was obtained from the previous information and bank height. The volume of sediment lost was determined using lengths of shoreline reaches. Biggs determined the mass of sediment eroded in the middle bay to be 1.3×10^6 metric tons, of which 21% (2.75×10^5 metric tons) was silt and clay. For the middle bay, 52% of the suspended sediment budget was attributed to shoreline erosion. He also constructed a suspended sediment budget for the "upper bay" from the Susquehanna River south to the Chester River. For the upper bay, 13% of the suspended sediment budget was attributed to shoreline erosion. The total mass of sediment on which the upper bay budget was based was 7.58×10^5 metric tons.

Schubel and Carter (1976) constructed a suspended sediment model for the Chesapeake Bay. Several inorganic origins for silt and clay were identified as follows: fluvial inputs from the Susquehanna River, shoreline erosion inputs and oceanic inputs. The silt and clay contribution from shoreline erosion was a rough estimate based on data from previous research for the Bay north of the Potomac River plus an estimated contribution for the remainder of the Bay. They attributed 1.07×10^6 metric tons (57%) of suspended sediment to the Susquehanna River, approximately 6.0×10^5 metric tons (32%) to shoreline erosion and approximately 2.2×10^5 metric tons (12%) to oceanic inputs. Their model used salt flux equations to determine suspended sediment fluxes. The model identified the Bay as a source of suspended sediment to the tributaries while the tributaries were sinks for suspended sediment.

Byrne et al. (1982) developed an inorganic sediment budget for the Virginia portion of the Bay. Their study examined the total sediment budget, not just the suspended sediment portion. The sediment components represented in their budget include contributions from the Maryland section of the Bay, Virginia's major tributaries, oceanic sources, shoreline erosion, shell material, planktonic skeletal material, and the material on the Bay floor. The findings of Biggs (1970) and Schubel and Carter (1976) were used as estimates for some of the components, while values for the other components were measured. The quantity of material eroded was obtained from Byrne and Anderson (1977). The percentages of sand, silt and clay were calculated by extrapolating measured values collected from fastland and beach samples. The samples were taken ap-

proximately every mile along the main Bay. They determined that shoreline erosion in Virginia accounted for 2.5×10^4 metric tons of silt and clay per year, an estimate an order of magnitude less than Schubel and Carter's estimate (2.0×10^5 metric tons per year) for Virginia's silt and clay shore erosion contribution. Byrne et al. (1982) reported shore erosion in Virginia accounted for 6% of the 4.0×10^5 metric tons of suspended sediment in the budget. The Byrne et al. (1982) study also gave a measured value for the sand component from Virginia's shore erosion as 4.0×10^5 metric tons per year.

Lukin (1983) constructed a sediment budget for the Rappahannock River. He identified 4 sediment sources: shoreline erosion, suspended sediment from the Chesapeake Bay, suspended sediment from the coastal plain and suspended sediment from the Blue Ridge-Piedmont Sub-basin (west of the fall line). Using the work of Byrne and Anderson (1977) and two different estimates of the bulk density of shoreline sediments, he estimated the sediment contribution from shoreline erosion to vary from 52% to 75% of the total budget. However, his work did not estimate the proportion of silt and clay since no fastland grain size measurements were obtained. He also concluded that there was a net deposition of sediment in the Rappahannock River.

Miller (1983) constructed a sediment budget for the Potomac River from the Chesapeake Bay to the fall line. He examined the mass of sediment contributed from shoreline erosion and developed an historical, a modern and an adjusted modern estimate of the soil lost to shoreline erosion. The adjusted modern estimate incorporated the reduction in erosion due to shoreline erosion control structures. Miller obtained soil samples from fastland banks and determined the percent of silt and clay to be roughly 40% of the total mass eroded. Miller developed a suspended sediment budget for the entire Potomac River and identified the following influx components: the Potomac River above Chain Bridge, tributary creeks and rivers, shoreline erosion and the Chesapeake Bay. The silt and clay contribution from shoreline erosion to the entire suspended sediment budget varied from approximately 6% to 9%. South of the Route 301 bridge, the contribution from shoreline erosion was greater, resulting in a silt and clay contribution of approximately 11% to 18%. Miller also noted the variation in bulk density values used in other

sediment budget studies and the impact such values had on the reported mass of material eroded.

II. SITE DESCRIPTION AND SAMPLING PROCEDURES

Site Selection

Fourteen sites were selected for the project using the data in Byrne and Anderson (1977), the U.S. Army Corps of Engineers (1986) and the VIMS Shoreline Inventory Computer Database (unpublished) to identify shoreline "reaches" with historical erosion rates of greater than 2.0 feet per year and erosion volumes of greater than 1.0 cubic yard per foot per year. The VIMS Shoreline Inventory Computer Database also provided information on the presence of living marine resources (clams, oysters or submerged aquatic vegetation) in the reaches. The reaches identified by the database were then examined for potential sampling sites. One sampling site was chosen per reach based on the accessibility and suitability for sampling. Sites with little or no vegetation on the bank slope were selected. Of the 4 Chesapeake Bay sites, 2 were located on the Eastern Shore of Virginia. Four of the remaining sites were located on the Rappahannock River, 3 on the James River, 2 on the Potomac River and 1 on the York River. Site locations are depicted in Figure 1. Site names were primarily selected using landmarks identified on the U.S. Geological Survey topographic quadrangles. The site number, name, county, body of water, reach length (statute miles), erosion rate, volume eroded and presence of living marine resources data are presented in Table 1.

Sampling Procedures

Field sampling involved collection of soil samples from various horizons on the bank face. Samples were taken directly from the bank face where undisturbed sediments were present. It was necessary to dig down to undisturbed soils where sloughing had occurred. Samples were taken from each horizon for nutrient and grain size analyses. Samples were placed in sterile whirlpaks and the texture and color of sediment noted.

The sample positions and horizon endpoints were surveyed where slope conditions allowed. Horizons on steeper slopes were measured with a tape measure or surveyor's rod. Shore sample locations were surveyed

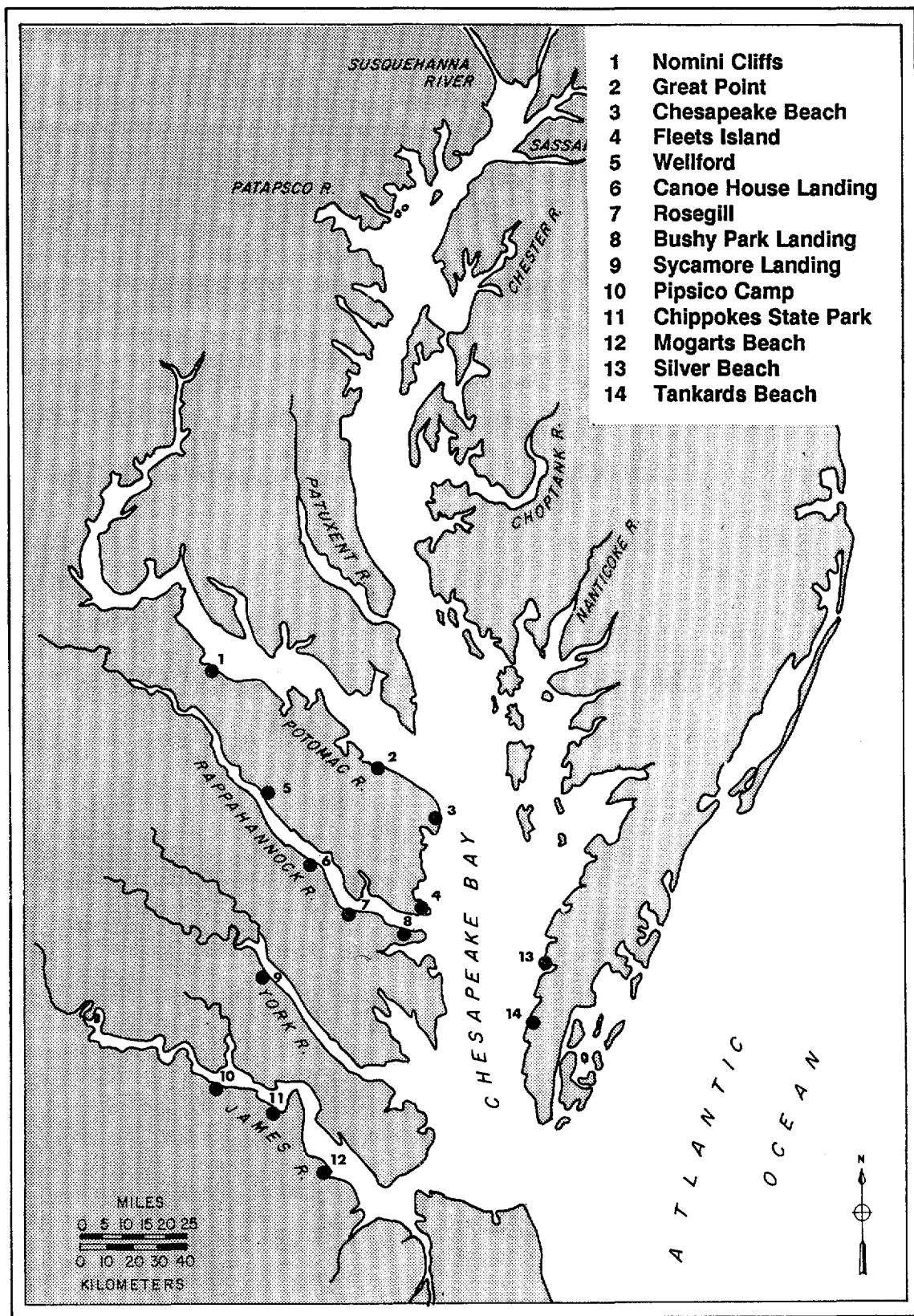


Figure 1. Site Locations.

Table 1. Site Information

<u>Site No.</u>	<u>Site Name</u>	<u>County</u>	<u>Body of Water</u>	<u>Reach Length (miles)</u>	<u>Erosion Rate (ft/yr)</u>	<u>Volume Eroded (cy/ft/yr)</u>	<u>Living Marine Resources</u>
1	Nomini Cliffs (NC)	Westmoreland	Potomac River	5.1	3.5	7.9	No
2	Great Point (GP)	Northumberland	Potomac River	0.8	10.6	2.1	Yes
3	Chesapeake Beach (CB)	Northumberland	Chesapeake Bay	3.3	6.1	2.3	Yes
4	Fleets Island (FI)	Lancaster	Chesapeake Bay	4.1	7.9	2.0	Yes
5	Wellford (WE)	Richmond	Rappahannock River	3.9	2.4	1.1	Yes
6	Canoe House Landing (CL)	Middlesex	Rappahannock River	2.9	6.5	1.3	Yes
7	Rosegill (RO)	Middlesex	Rappahannock River	1.0	2.3	1.6	Yes
8	Bushy Park Creek (BP)	Middlesex	Rappahannock River	0.7	3.1	3.1	Yes
9	Sycamore Landing (SL)	James City	York River	3.0	1.6	1.2	Yes
10	Pipsico Camp (PC)	Surry	James River	3.8	1.8	2.5	No
11	Chippokes State Park (CH)	Surry	James River	2.3	1.1	2.0	No
12	Mogarts Beach (MB)	Isle of Wight	James River	7.0	3.8	2.8	Yes
13	Silver Beach (SB)	Northampton	Chesapeake Bay	1.8	5.7	1.9	Yes
14	Tankards Beach (TB)	Northampton	Chesapeake Bay	1.3	7.0	2.1	Yes

or measured with a tape measure. Shore samples were obtained at locations on the backshore, foreshore and nearshore. The backshore is defined as the area between the base of the bank and mean high water. The foreshore is the intertidal zone or area between mean high and mean low water. The nearshore extends channelward of mean low water and was generally sampled adjacent to mean low water. See Figure 2 for an illustration of the site definitions.

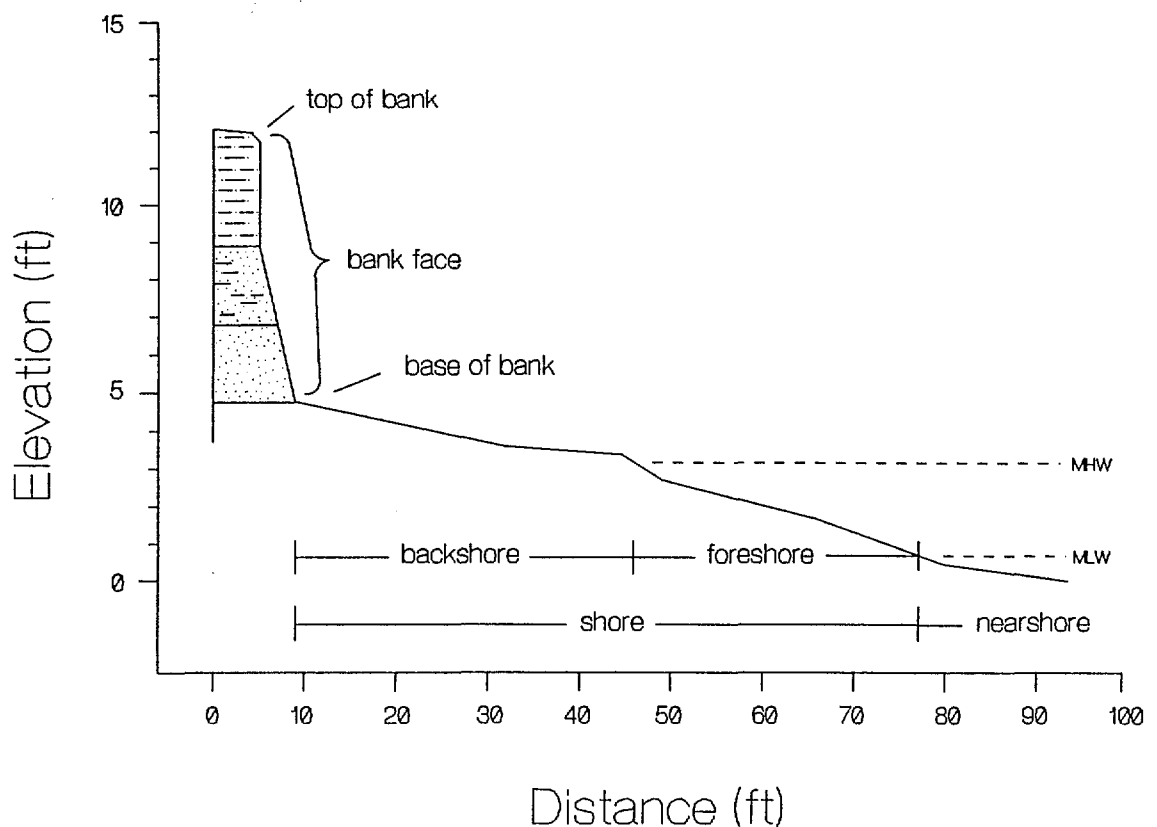







Figure 2. Site Definitions.

Site Description

The 14 sites are described and stratigraphic cross sections and sample locations presented graphically in the following section. The sites are described according to the numerical order presented in Figure 1. Reach characteristics and individual sampling site characteristics are discussed. The horizons shown on the cross sections are based on the grain size analysis of the soil samples as defined in Table 2.

Table 2. Soil Classification Criteria

<u>Symbol</u>	<u>Description</u>	<u>Composition</u>
	gravel and sand	greater than 60% sand with 20% or greater gravel
	sand	greater than 80% sand less than 20% silt and clay
	silty/clayey sand	50% to 80% sand 20% to 50% silt/clay
	sandy silt/clay	50% to 80% silt/clay 20% to 50% sand
	silt/clay	greater than 80% silt/clay less than 20% sand

Site 1: Nomini Cliffs (NC)

The Nomini Cliffs reach is located on the Potomac River in Westmoreland County. The reach extends for 26,700 feet or approximately 5.1 miles. The sampling site is located on a vacant lot in a subdivision just upriver from Westmoreland State Park. The bank has an elevation of 30 feet above mean low water and a nearly vertical slope. The Nomini Cliffs reach includes bluffs reaching 150 feet. The publication Soil Survey of Westmoreland County, Virginia (1981) classifies the upper soil horizons as Rumford and Tetotum. These soils are typically sandy and vary in color from dark brown to yellow with depth. Six bank face samples were taken. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 distinct horizons: silty/clayey sand, sand and sandy silt/clay. In addition, 3 shore samples were obtained. The backshore width is negligible.

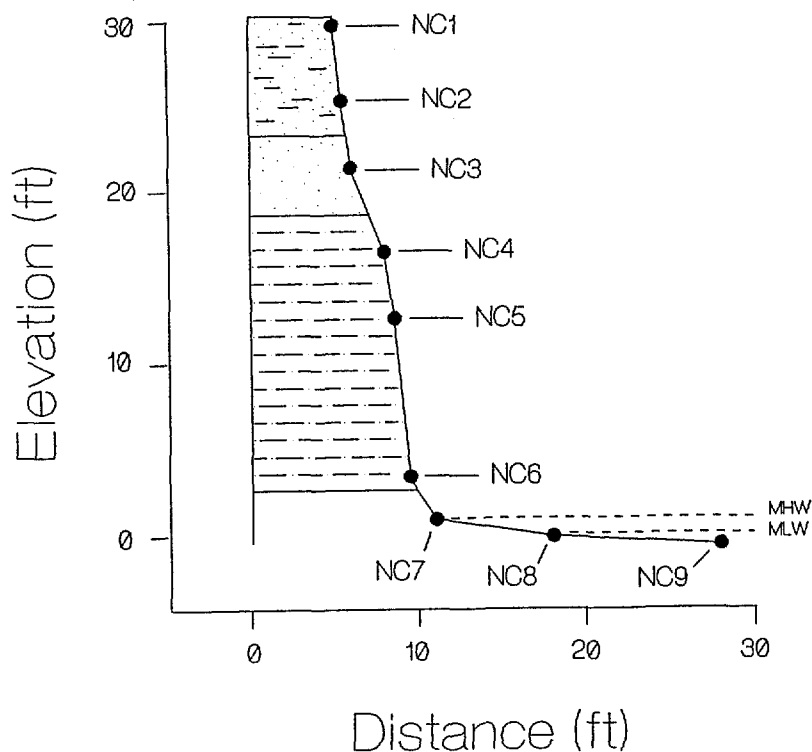


Figure 3. Stratigraphic cross section and sample locations - Nomini Cliffs.

Site 2: Great Point (GP)

Great Point is located on the Potomac River downriver from the Coan River in Northumberland County. The reach extends for 4,000 feet or approximately 0.8 mile. The sampling site is wooded. The bank has an elevation of 4.5 feet above mean low water with a slope of approximately 1.5:1 (horizontal/vertical). The publication Soil Survey of Northumberland and Lancaster Counties, Virginia (1963) classifies the upper soil horizons as Mattapex silt loam. Mattapex soil is described as brown in color and varying with depth from a silt loam to a silty/clay loam or sandy/clay loam to sand. Three bank face samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank consists of a sandy silt/clay. In addition, 3 shore samples were obtained. The backshore width is approximately 6.5 feet.

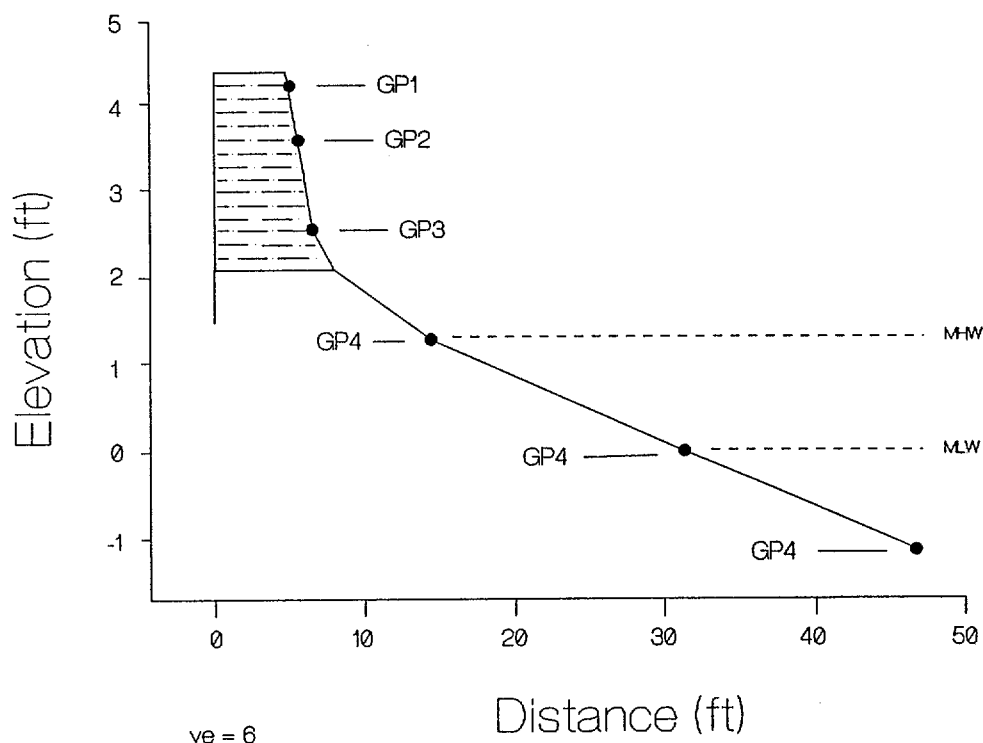


Figure 4. Stratigraphic cross section and sample locations - Great Point.

Site 3: Chesapeake Beach (CB)

The Chesapeake Beach site is located on the Chesapeake Bay south of Gaskin Pond in Northumberland County. The reach extends for 17,200 feet or approximately 3.3 miles. The sampling site is a residential property with a small cottage. The bank has an elevation of 10 feet above mean low water and an approximate upper slope of 1:1 (horizontal/-vertical) with a flatter portion at the base. Although a groin system and riprap sill are present on the property, the bank continues to erode. The publication Soil Survey of Northumberland and Lancaster Counties, Virginia (1963) classifies the upper soil horizons as "sloping sandy land." The soil is described as primarily sandy, but is quite variable in composition. Four bank face samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 distinct horizons: silt/clay, sandy silt/clay and sand. Four shore samples were also obtained. The riprap sill is located between the points CB4 and CB5 in Figure 5 below. The backshore width is influenced by the presence of the sill and is approximately 26 feet wide. The most seaward shore sample was obtained with a bucket auger and contained clay.

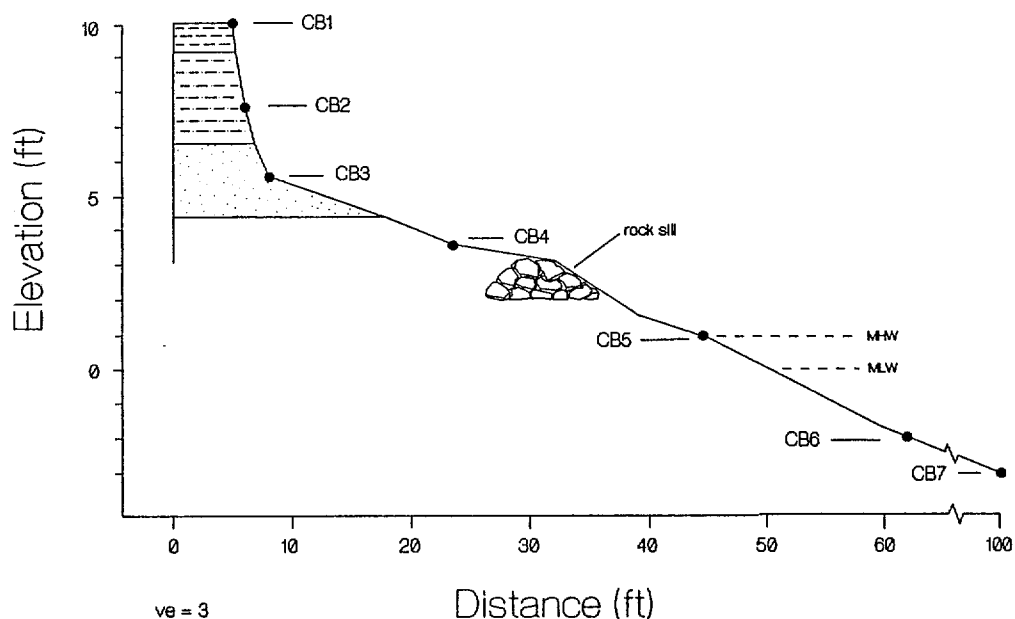


Figure 5. Stratigraphic cross section and sample locations - Chesapeake Beach.

Site 4: Fleets Island (FI)

The Fleets Island site is located on the Chesapeake Bay in Lancaster County. The reach extends for 21,500 feet or approximately 4.1 miles. The site is wooded. The bank has an elevation of 4.5 feet above mean low water. The bank face is irregularly shaped due to differential erosion of the clay base versus the overlying sandy soil and has an approximate slope of 5:1 (horizontal/vertical). The publication Soil Survey of Northumberland and Lancaster Counties, Virginia (1963) classifies the upper soil horizons as Othello silt loam. The soil is described as poorly drained and composed of silt loam grading to clay loams grading to sand. Three bank samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank has 2 horizons: sand and sandy silt/clay. Four shore samples were also obtained. The backshore width is 7 feet.

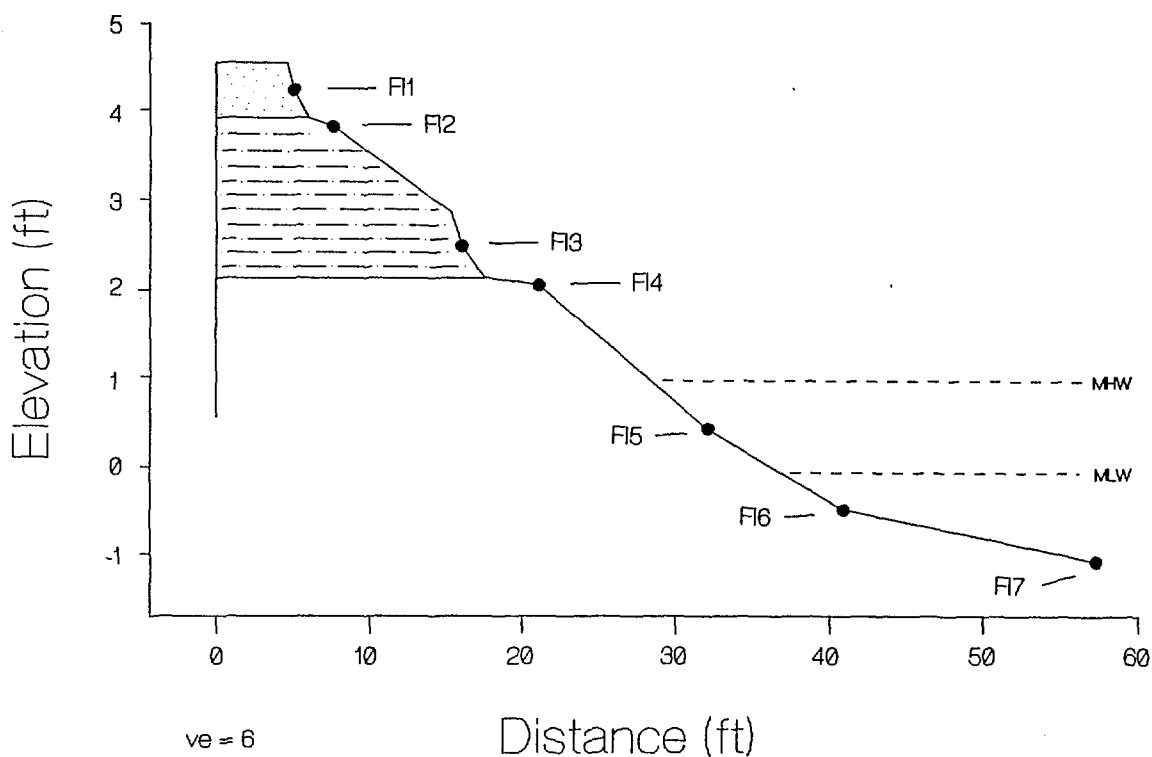


Figure 6. Stratigraphic cross section and sample locations - Fleets Island.

Site 5: Wellford (WE)

The Wellford site is located on the Rappahannock River in Richmond County. The reach extends for 20,400 feet or approximately 3.9 miles. The sampling site is located on a wooded bluff adjacent to agricultural fields and a small stream. The bank height is nearly 20 feet above mean low water and the slope is approximately vertical. The publication Soil Survey of Richmond County, Virginia (1982) classifies the upper soil horizons as Suffolk sandy loam. The soil is described as well drained and varies from a sandy loam to loam or loamy sand with depth. Five bank face samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 distinct horizons: sand, gravel and sand, and silty/clayey sand. In addition, 3 shore samples were obtained. The backshore width is negligible.

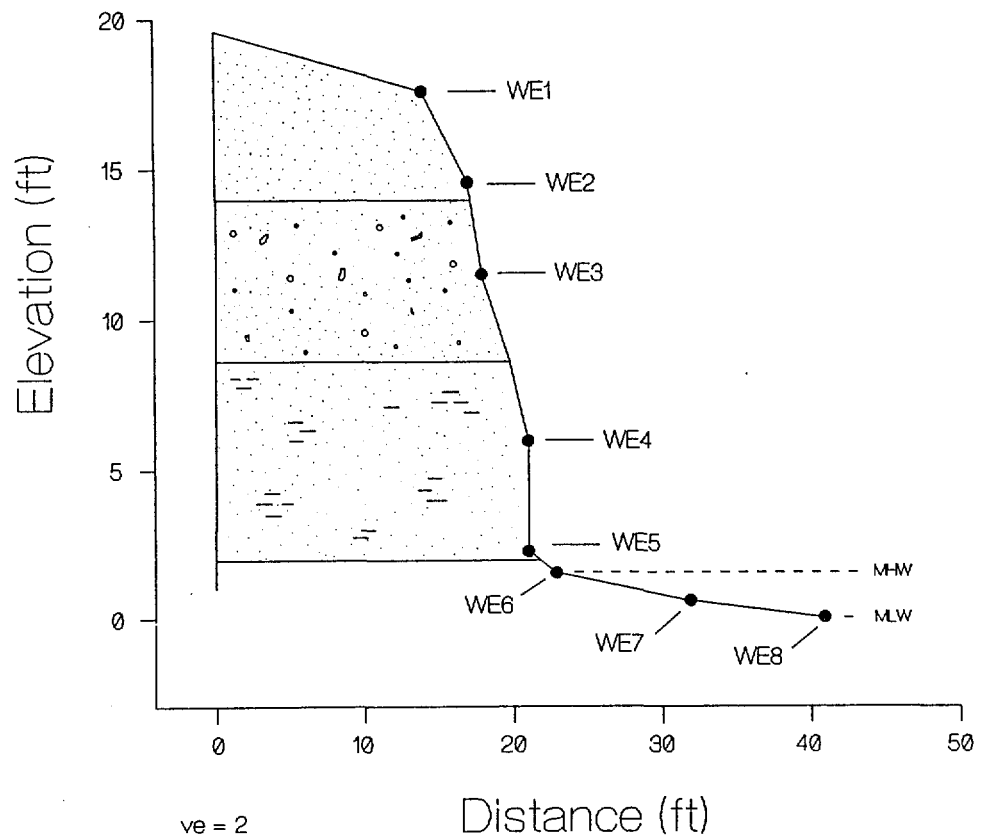


Figure 7. Stratigraphic cross section and sample locations - Wellford.

Site 6: Canoe House Landing (CL)

The Canoe House Landing site is located east of Bayport on the Rappahannock River in Middlesex County. The reach extends for 15,500 feet or approximately 2.9 miles of shoreline. The sampling site is located on a wooded property with a summer cottage and is downriver from the Canoe House Landing public beach. The bank has an elevation of 40 feet above mean low water and a slope slightly steeper than 1:1 (horizontal/vertical). The publication Soil Survey of Middlesex County, Virginia (1985) classifies the upper soil horizons as Kempsville sandy loam. The upper horizons are described as well drained, with brown sandy loam grading to sandy clay loam with depth. Ten bank face samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank has 6 distinct horizons: silty/clayey sand, sand, silty/clayey sand, silt/clay, sandy silt/clay and sand. Three shore samples were also obtained. The backshore width is 15 feet.

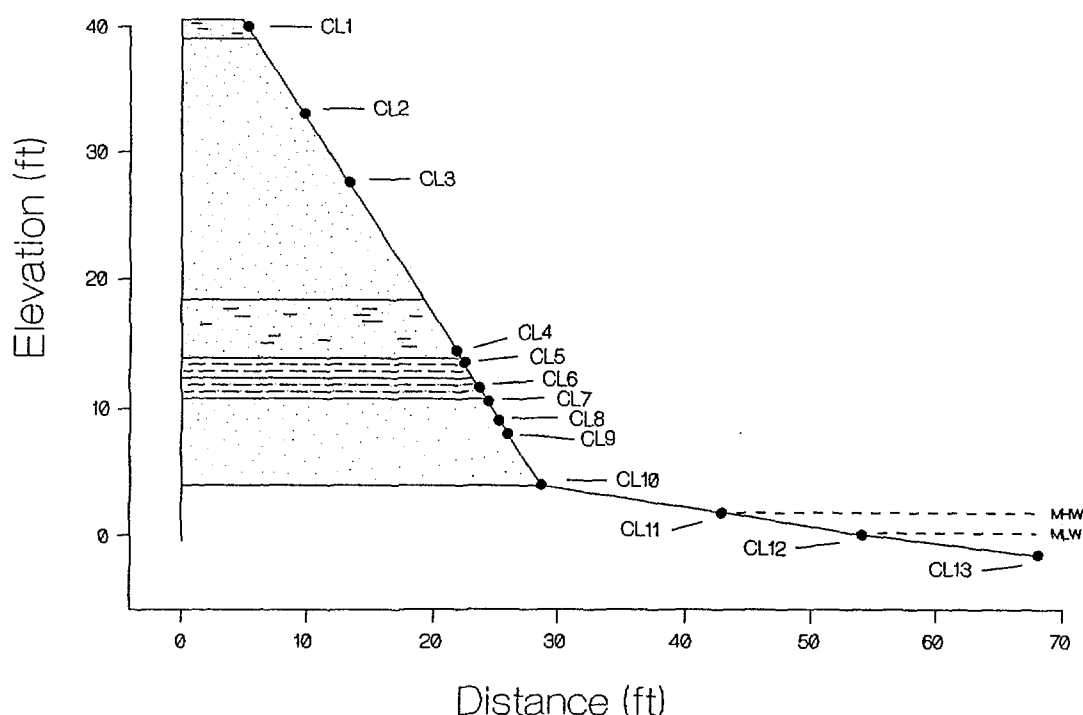


Figure 8. Stratigraphic cross section and sample locations - Canoe House Landing.

Site 7: Rosegill (RO)

The Rosegill site is located east of Urbanna Creek on the Rappahannock River in Middlesex County. The reach extends for 5,400 feet or approximately 1 mile. The site is adjacent to an agricultural field. The bank has an elevation of approximately 24 feet above mean low water and an irregular slope of approximately 1:1 (horizontal/vertical). The publication Soil Survey of Middlesex County, Virginia (1985) defines the upper soil horizons as Suffolk-Remlik complex. The upper horizons are primarily sandy loam grading to a loamy sand with depth. Nine samples were obtained from the bank face because of the variation in soil color in the lower part of the bank. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 distinct horizons: sand, gravel and sand, and sand. Three shore samples were also obtained. The backshore width is approximately 5 feet.

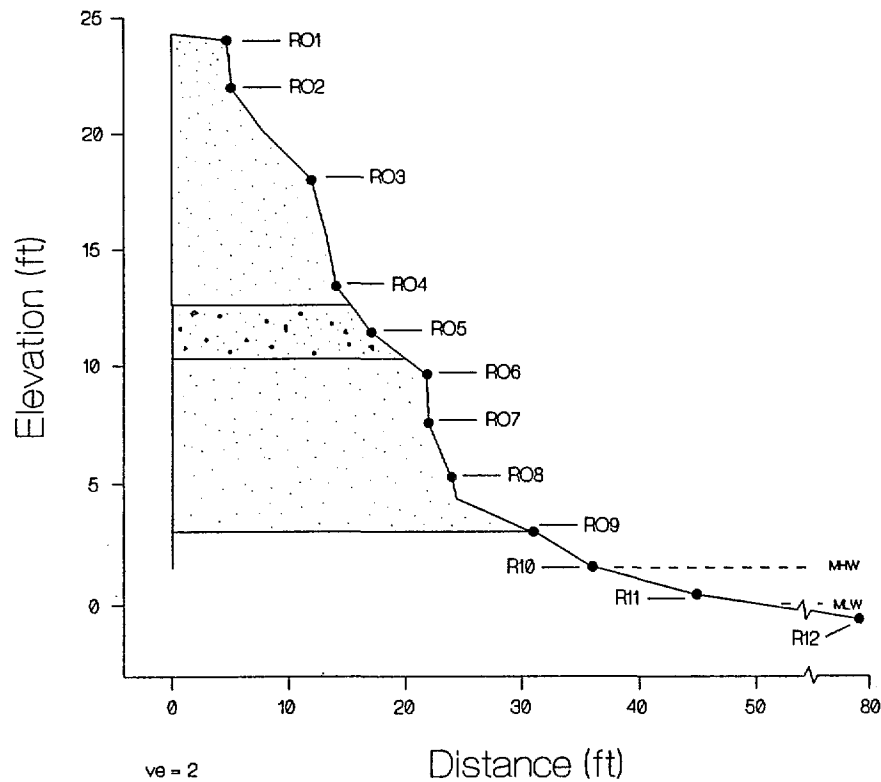


Figure 9. Stratigraphic cross section and sample locations - Rosegill.

Site 8: Bushy Park Creek (BP)

The Bushy Park Creek site is located on a residential property east of Bushy Park Creek on the Rappahannock River in Middlesex County. The reach extends for 3,600 linear feet or approximately 0.7 mile of shoreline. Although a groin system had been installed on the property, active bank sloughing is still occurring. The bank has an elevation of 40 feet above mean low water and the slope is approximately 1:1 (horizontal/vertical). The publication Soil Survey of Middlesex County, Virginia (1985) classifies the upper soil horizons as Suffolk fine sandy loam. The soil is described as a well drained, yellowish to brown sandy loam grading to a loamy sand with depth. Eight bank face samples were taken. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 distinct horizons: sand, sandy silt/clay and sand. Three shore samples were taken. The backshore width is approximately 25 feet. The groin system affects the beach width. Figure 10 provides a cross section of the site and sample locations.

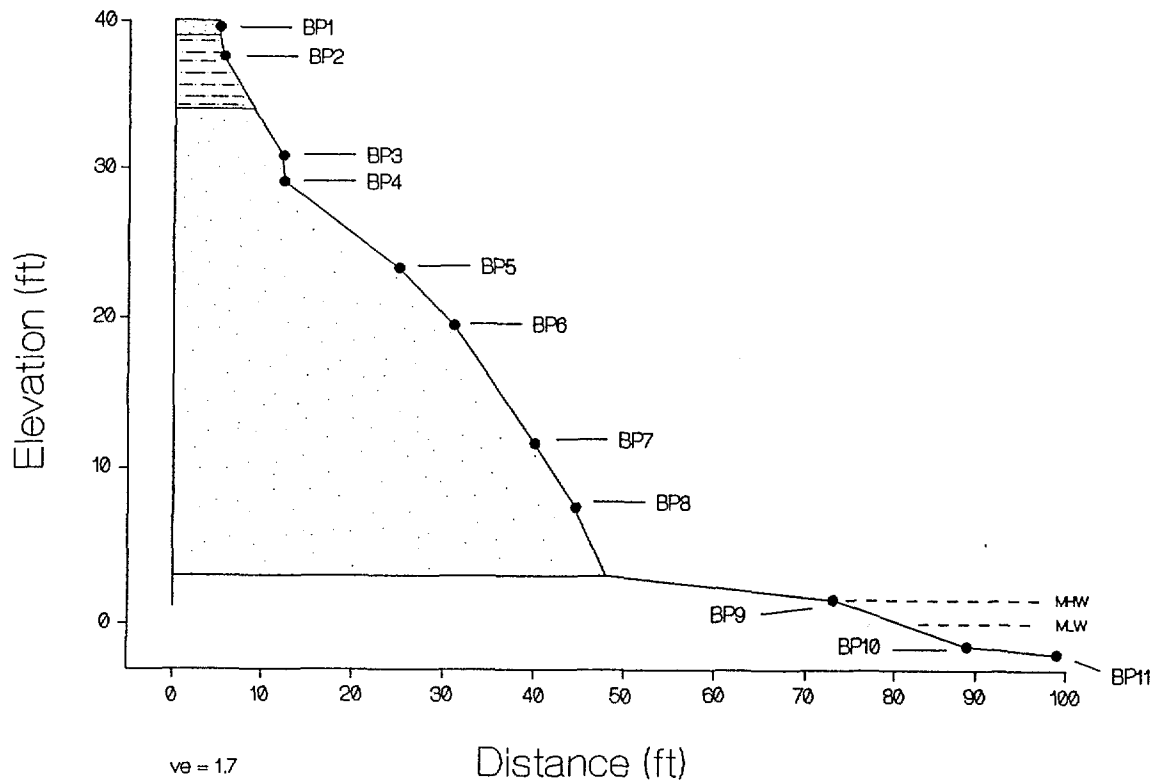


Figure 10. Stratigraphic cross section and sample locations - Bushy Park Creek.

Site 9: Sycamore Landing (SL)

The Sycamore Landing site is located upriver from York River State Park on the York River in James City County. The reach extends for 15,700 feet or approximately 3 miles. The sampling site is located in a wooded area adjacent to a subdivision. The bank has an elevation of approximately 54 feet above mean low water. The lower slope is approximately 1:1 (horizontal/vertical) below the vertical top portion. The publication Soil Survey of James City and York Counties and the City of Williamsburg, Virginia (1985) classifies the upper soil horizons as Emporia complex. The soils are described as steep, well drained and having fossil rich layers underneath. Eight samples were obtained from the bank face. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 horizons: silty/clayey sand, sandy silt/clay and sand. Three shore samples were also obtained. The backshore width is approximately 6 feet.

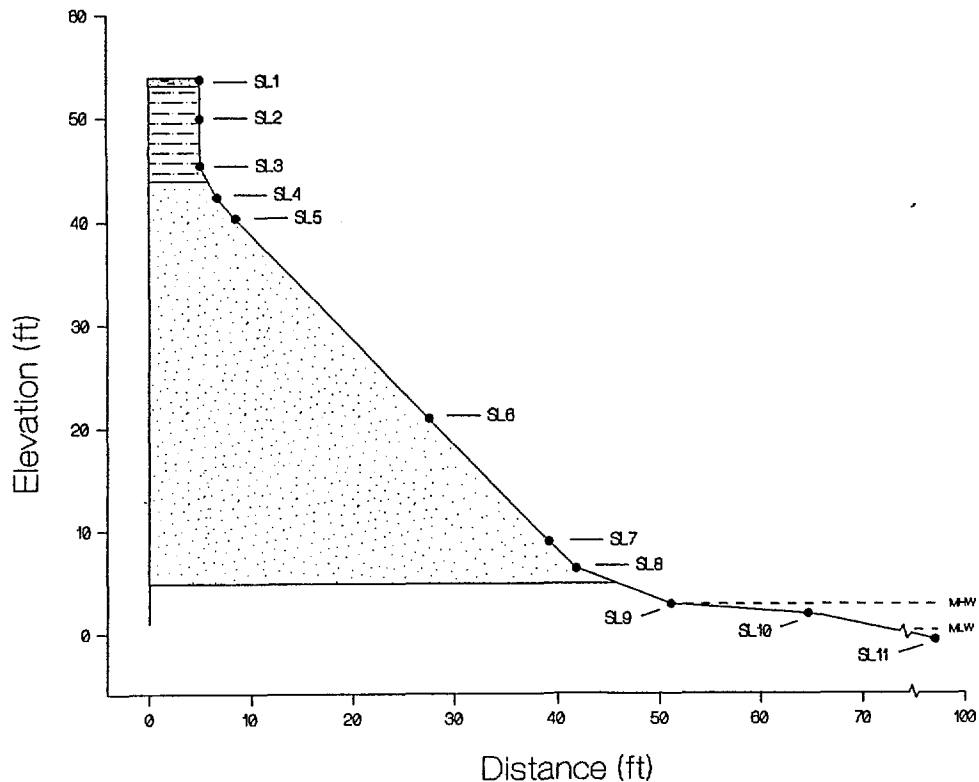


Figure 11. Stratigraphic cross section and sample locations - Sycamore Landing.

Site 10: Pipsico Camp (PC)

Pipsico Boy Scout Camp is located on the James River in Surry County. The reach extends for 20,200 feet or approximately 3.8 miles. The sampling site is adjacent to the rifle range at the Scout camp. The bank has an elevation of approximately 65 feet above mean low water. The lower slope is approximately 1:1 (horizontal/vertical) below the steeper top section. Recent unpublished soil survey data for Surry County classifies the upper soil horizons of the bank face as Nevarc-Remlik gravelly complex. Inland from the bank face, the upper soil horizons are classified as Uchee loamy sand. Seven bank face samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank has 4 distinct horizons: silty/clayey sand, silt/clay, silty/clayey sand and sand. Four shore samples were also obtained. The backshore width is approximately 15 feet.

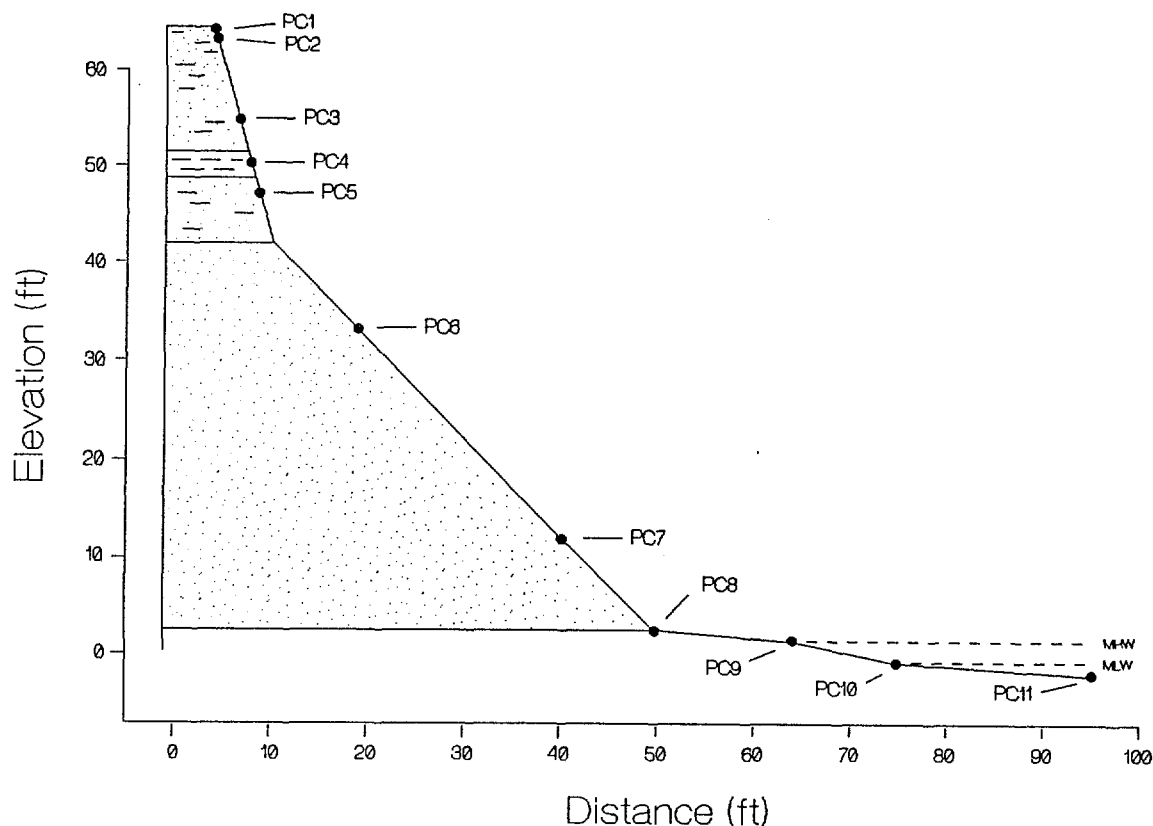


Figure 12. Stratigraphic cross section and sample locations - Pipsico Camp.

Site 11: Chippokes State Park (CH)

Chippokes Plantation State Park is located on the James River in Surry County. The reach extends for 12,000 feet or approximately 2.3 miles. The sampling site is adjacent to a large pasture on the model farm and downriver of a gapped breakwater system. The bank has an elevation of approximately 47 feet above mean low water with a nearly vertical slope. Recent unpublished soil survey data for Surry County classifies the upper soil horizons of the bank face as Nevarc-Remlik complex. Inland from the bank face, the upper soil horizons are classified as Newflat silt loam. Six bank face samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank has 4 distinct horizons: sandy silt/clay, silty/clayey sand, sandy silt/clay and silty/clayey sand. Four shore samples were also obtained. The backshore width is approximately 16 feet.

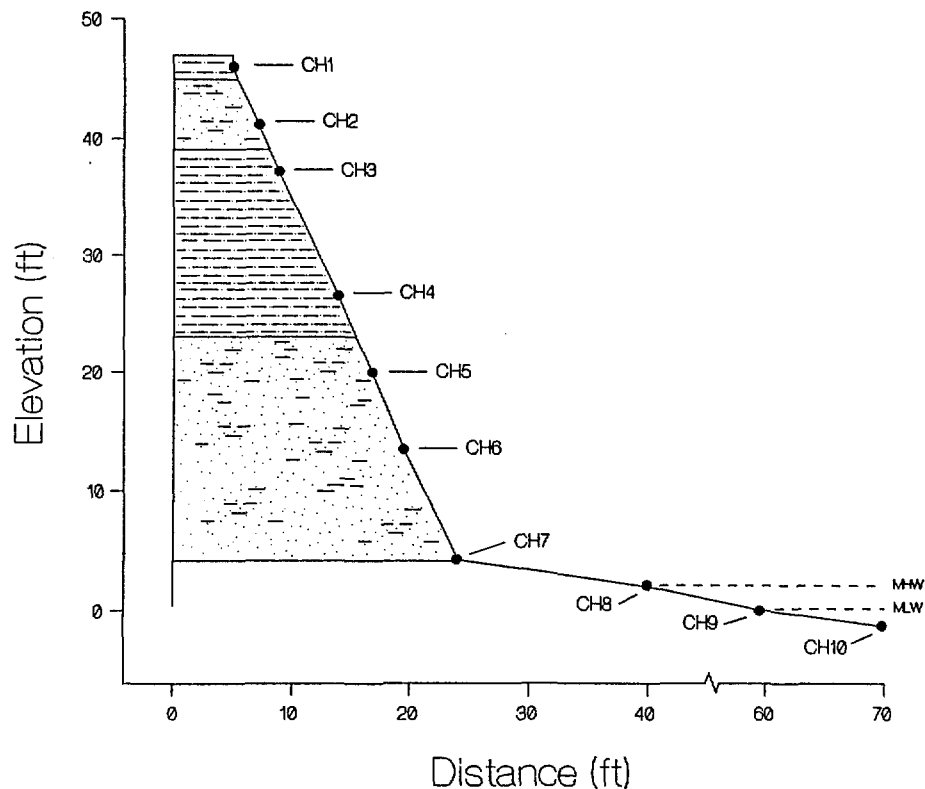


Figure 13. Stratigraphic cross section and sample locations - Chippokes State Park.

Site 12: Mogarts Beach (MB)

Mogarts Beach is located on the James River upriver from the Pagan River in Isle of Wight County. The reach extends for 36,800 feet or approximately 7 miles. The sampling site is a vacant lot adjacent to a residence. The bank has an elevation of 26 feet above mean low water and a nearly vertical slope. The publication Soil Survey of Isle of Wight County, Virginia (1986) classifies the upper soil horizons as Peawick silt loam. Peawick silt loam varies from a silt loam to a clay loam with depth. Four bank face samples were obtained. According to grain size analysis and the soil classification criteria in Table 2, the bank has 2 distinct horizons: sandy silt/clay and silty/clayey sand. The lower section of the bank is a dense marine clay that proved to have a fairly high sand content. In addition, 3 shore samples were obtained. The backshore width is 7 feet.

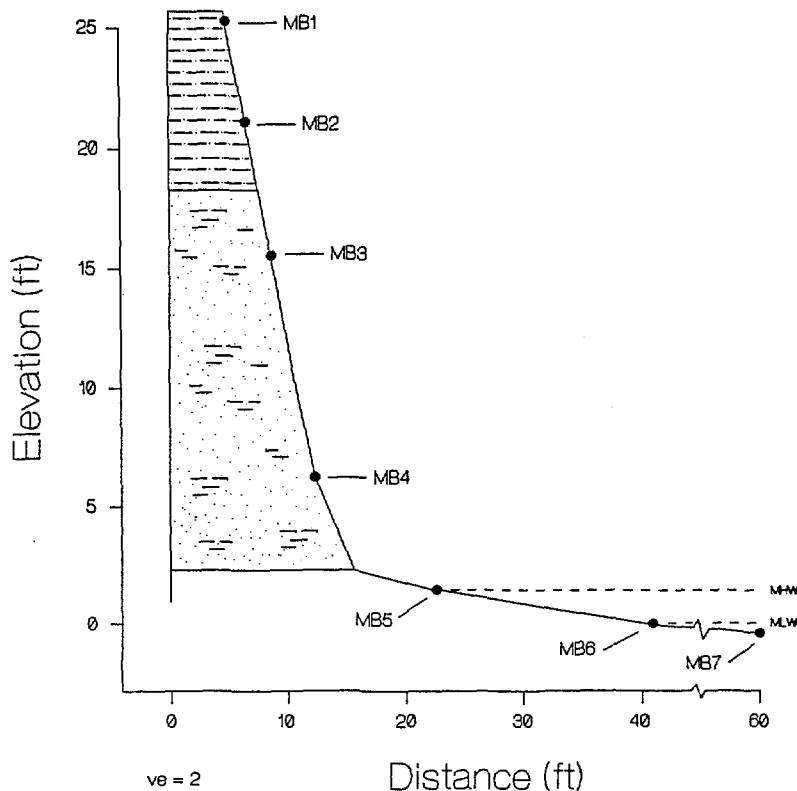


Figure 14. Stratigraphic cross section and sample locations - Mogarts Beach.

Site 13: Silver Beach (SB)

The Silver Beach reach is a section of agricultural land and summer cottages on the Chesapeake Bay in Northampton County. The reach extends for 9,700 feet or approximately 1.8 miles. The sampling site is located at the agricultural field immediately south of Silver Beach. The property was recently subdivided and sold for residential development. The bank has an elevation of 15 feet above mean low water and a nearly vertical slope. Recent unpublished soil survey data classifies the upper horizons as Bojac loamy sand. Four bank face samples were taken. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 distinct horizons: silty/clayey sand, sandy silt/clay and sand. Three shore samples were also obtained. The backshore width is approximately 9 feet.

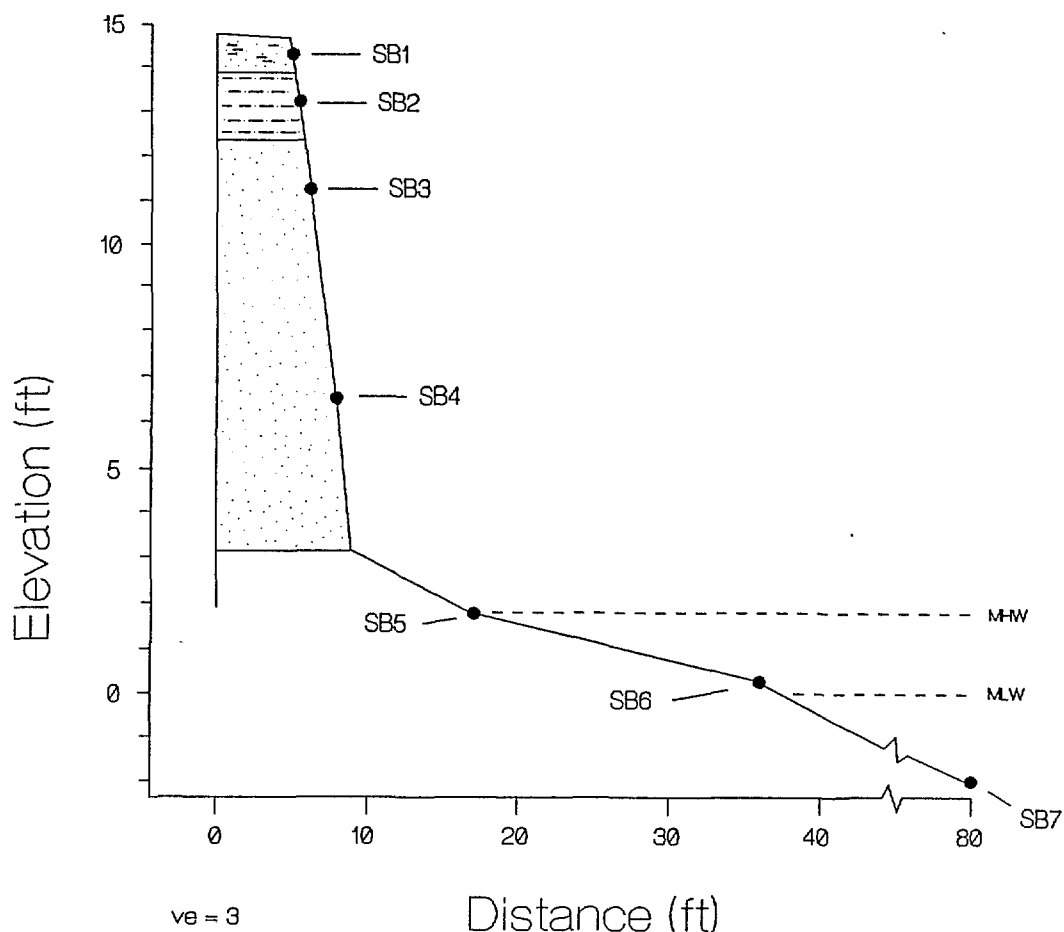


Figure 15. Stratigraphic cross section and sample locations - Silver Beach.

Site 14: Tankards Beach (TB)

The Tankards Beach site is located on the Chesapeake Bay in Northampton County. The reach extends for 7,000 feet or approximately 1.3 miles. The sampling site is an agricultural field. The bank has an elevation of 12 feet above mean low water and a nearly vertical slope. Recent unpublished soil survey data classifies the upper soil horizons as Bojac loamy sand. Four bank face samples were taken. According to grain size analysis and the soil classification criteria in Table 2, the bank has 3 distinct horizons: sandy silt/clay, silty/clayey sand and sand. Four shore samples were also obtained. The backshore width is 32 feet.

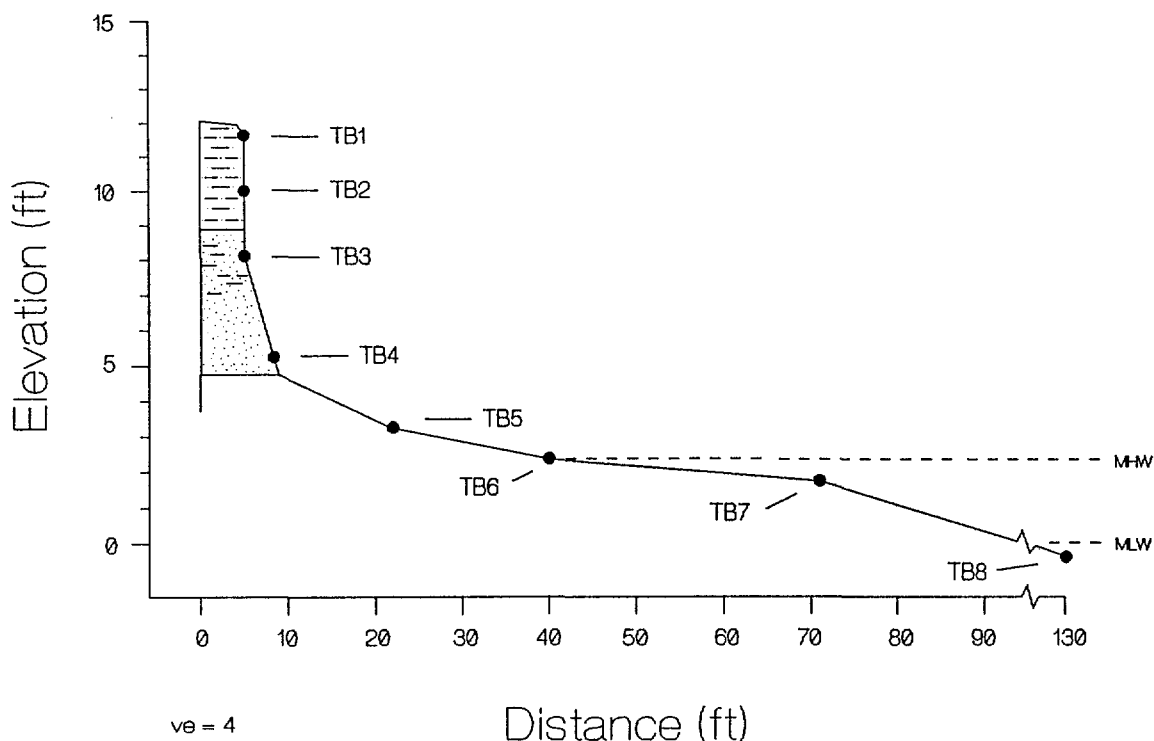


Figure 16. Stratigraphic cross section and sample locations - Tankards Beach.

III. METHODOLOGY

Laboratory Analyses

Laboratory analyses were conducted by the Virginia Institute of Marine Science sediment and water quality labs. The water quality lab uses EPA approved procedures.

Nutrient Analyses

The total nitrogen (TN) determination included nitrate nitrogen and total Kjeldahl nitrogen (TKN; includes ammonia and organic forms of nitrogen). TN analysis procedures can be found in the Carlo Erba Strumentazione Carbon Nitrogen Analyzer 1500 Instruction Manual (1986). TN analysis was conducted using 10 to 20 mg samples of air-dried, ground soil. Each soil sample was analyzed for TN using a Carlo Erba NA1500 C/N Analyzer. The mean detection limit for TN was 0.18 mg/g.

Phosphorus determinations included total phosphorus (TP) and inorganic phosphorus (IP; orthophosphate). Phosphorus procedures were taken from the following reference manuals: "Laboratory Procedure for the Soil Testing and Plant Analysis Laboratory" (1988) and Methods for Chemical Analysis of Water and Wastes (1974). TP and IP were measured by extraction and ignition of approximately 1 g samples of air-dried, homogenized, ground soil. The samples were combusted at 475 °C for 5 hours. TP was extracted from the ashed sample using HCl, while IP was extracted with HCl and H₂SO₄. Sample extracts were filtered through Whatman G/F glass fiber filters and then analyzed using a continuous flow analyzer. The mean detection limit for TP was 0.01 mg/g and 0.001 mg/g for IP.

Grain Size Analysis

The sediment samples were split, wet sieved and separated into the gravel, sand, silt and clay fractions. To determine a weight percent, the gravel fraction (material coarser than 2.0 mm) was dried and weighed. The sand fraction (0.0625 to 2.0 mm) was analyzed using a rapid sediment analyzer (RSA) to determine the grain size distribution

and weight percent. The weight percentages of the silt and clay fractions (material finer than 0.0625 mm) were measured according to standard pipette methods.

Nutrient Differences among the Sites

Because the scope of this project covered a large geographic area and many different soil types, analysis of variance (ANOVA) was used to determine if any of the banks were "richer" in nutrients than the others. Specifically, the analysis of variance tested whether or not significant differences exist in the nutrient concentration levels among the banks sampled. Because of the variability in bank height and number of samples per site, the analysis of variance was conducted using 3 samples from each bank. A top of bank (topsoil), a midbank and a base of bank sample were selected for each site.

Nutrient Loading Rates

Nutrient loading rates were calculated for each site using the following information: nutrient concentration, estimated average bulk density, bank height, horizon thickness and annual erosion rate. All of the above variables were known except bulk density. The limited scope of the study did not allow field measurements of the bulk densities of the soils sampled. Therefore, we used an estimated average bulk density of 1.5 g/cm^3 . The bulk density value used was based on conversations with soil scientists and researchers from VPI&SU. Moreover, the value used was similar to the bulk densities reported in the soil surveys for some of the soils studied. Finally, the sediment budget literature reports great variability in the bulk densities used for sediment budget calculations. Miller (1983) used 1.67 g/cm^3 , the average dry bulk density from Pleistocene sediment test borings. Miller noted bulk density values used by other researchers which varied from 1.4 to 2.65 g/cm^3 (Schubel, 1968; Biggs, 1970; Byrne et al., 1982 and Lukin, 1983).

To calculate a nutrient loading rate for each site, the bank erosion volume was first calculated using the following equation:

$$V = B E W \quad (1)$$

where: V - Unit bank erosion volume (ft³/ft-yr)
 B - Bank height (ft)
 E - Unit erosion rate (ft/ft-yr)
 W - Unit width (1 ft)

Nutrient loading rates were then derived using the following equation:

$$R = \sum \left(\frac{H}{B} V N D C \right) \quad (2)$$

where: R - Nutrient loading rate (lbs/ft-yr)
 B - Bank height (ft)
 D - Bulk density (1.5 g/cm³)
 H - Horizon thickness (ft)
 N - Nutrient concentration (mg/g)
 V - Unit bank erosion volume (ft³/ft-yr)
 C - Conversion factor to English units (0.062)

Nutrient Concentration, Grain Size and Bank Height

Nutrient concentration, grain size and elevation were graphically compared to determine if any relationships were apparent. Linear regression analysis was performed to test for possible significant relationships between nutrient concentration and grain size.

IV. RESULTS

Grain Size of Fastland versus Shore Sediments

Fastland sediments had higher percentages of silt and clay than shore sediments, as would be expected. Approximately 70% of the bank samples had more than 10% silt and clay in contrast to 7% of the shore samples with the same silt and clay content. The lower silt and clay content of shore samples results from winnowing by waves and dispersal of finer grained fractions offshore. Moreover, littoral drift transports shore sediments, making the origin of the sediments difficult to identify. Appendices A and B list the grain size data for the fastland and shore samples.

Nutrient Concentrations and Loading Rates

Total nitrogen concentrations ranged from 0.01 to 3.34 mg/g for the fastland bank samples. Total phosphorus varied from 0.01 to 1.28 mg/g. No significant differences were found among the 14 sites in either nitrogen or phosphorus concentrations according to the analysis of variance test results. Thus no site was significantly "richer" in nutrients than the others. Nutrient concentrations are presented in Appendix A.

Although the range of nutrient concentrations among the 14 sites was small, large differences were found in nutrient loading rates due to the influence of physical conditions such as bank height and erosion rate on the calculated volume rates (Figure 17). Total nitrogen loading rates varied from 0.14 to 6.44 pounds per foot per year and total phosphorus loading rates varied from 0.04 to 4.42 pounds per foot per year. Moreover, sites with high loading rates of one nutrient did not always contribute equivalent amounts of the other nutrient. (Loading rate calculations for the sites are provided in Appendix C.)

The highest nitrogen loading rates were observed at Canoe House Landing (Site 6) and Nomini Cliffs (Site 1). The high nitrogen loading rate of 6.44 pounds per foot per year at Canoe House Landing can be attributed to the high nitrogen concentration found in the rich, organic

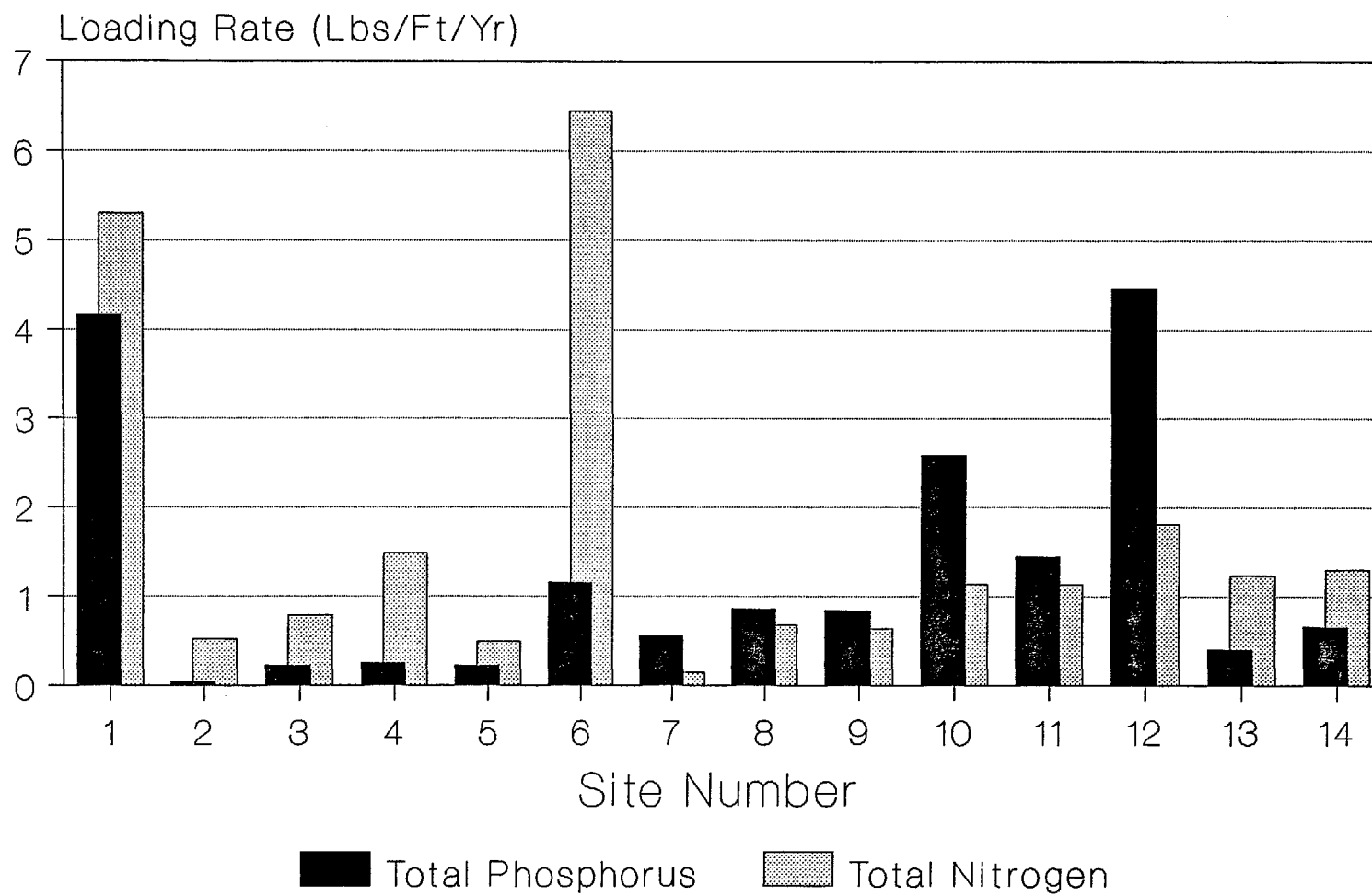


Figure 17. Nitrogen and phosphorus loading rates.

sandy silt/clay horizon and the relatively high erosion rate. Nomini Cliffs had a nitrogen loading rate of 5.30 pounds per foot per year. The high rate was due to high nitrogen concentrations in the topsoil and in the deeper sandy silt/clay horizon.

Phosphorus loading rates were highest for Mogarts Beach (Site 12), Nomini Cliffs (Site 1) and Pipsico Camp (Site 10). The phosphorus loading rates at the three sites were 4.42, 4.16 and 2.59 pounds per foot per year. Mogarts Beach had high phosphorus concentrations throughout the lower profile. At Nomini Cliffs, the phosphorus values were low in the upper horizons but increased markedly with depth in the sandy silt/clay layer. At Pipsico Camp, phosphorus concentrations were high in the silt/clay horizon and the silty/clayey sand directly beneath.

Nutrient Concentration, Grain Size and Bank Height

Grain size and total nitrogen and total phosphorus concentrations are plotted against bank height for each site in Figures 18 through 24. Grain size analysis revealed that the clay base at Great Point (Site 2), Fleets Island (Site 4) and the "marine clay" base at Nomini Cliffs (Site 1), Wellford (Site 5), Rosegill (Site 7), Sycamore Landing (Site 9) and Mogarts Beach (Site 12) have a higher sand concentration than expected. According to grain size analysis, Nomini Cliffs, Great Point and Fleets Island have a sandy silt/clay base. The marine clay base at Wellford and Mogarts Beach is a silty/clayey sand, while the marine clay layer at Rosegill and Sycamore Landing is classified as sand.

Nitrogen concentrations at each site showed a more consistent relationship with grain size and bank height than the phosphorus concentrations (Figures 18 through 24). Profiles typically showed peak nitrogen concentrations in upper soil layers and lower, more constant values throughout the remaining profile. Exceptions to the pattern occurred at Nomini Cliffs (Site 1), Wellford (Site 5), Canoe House Landing (Site 6), Sycamore Landing (Site 9) and Pipsico Camp (Site 10) where finer grained layers were found in the profile. In these cases, finer grained sediments had higher nitrogen concentrations than the other horizons. Fleets Island had a lower nutrient concentration in the "topsoil" (actually an overwash sand layer).

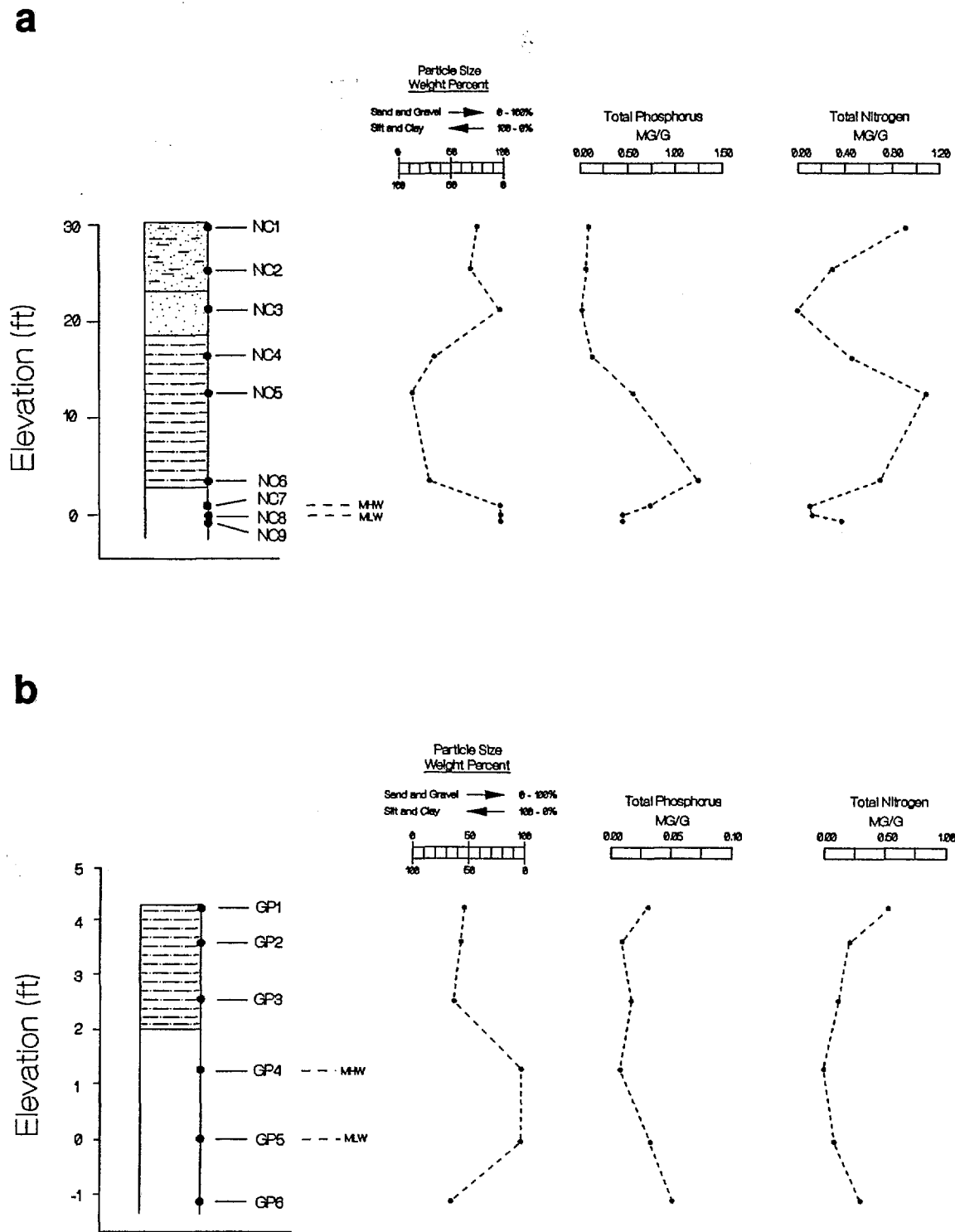
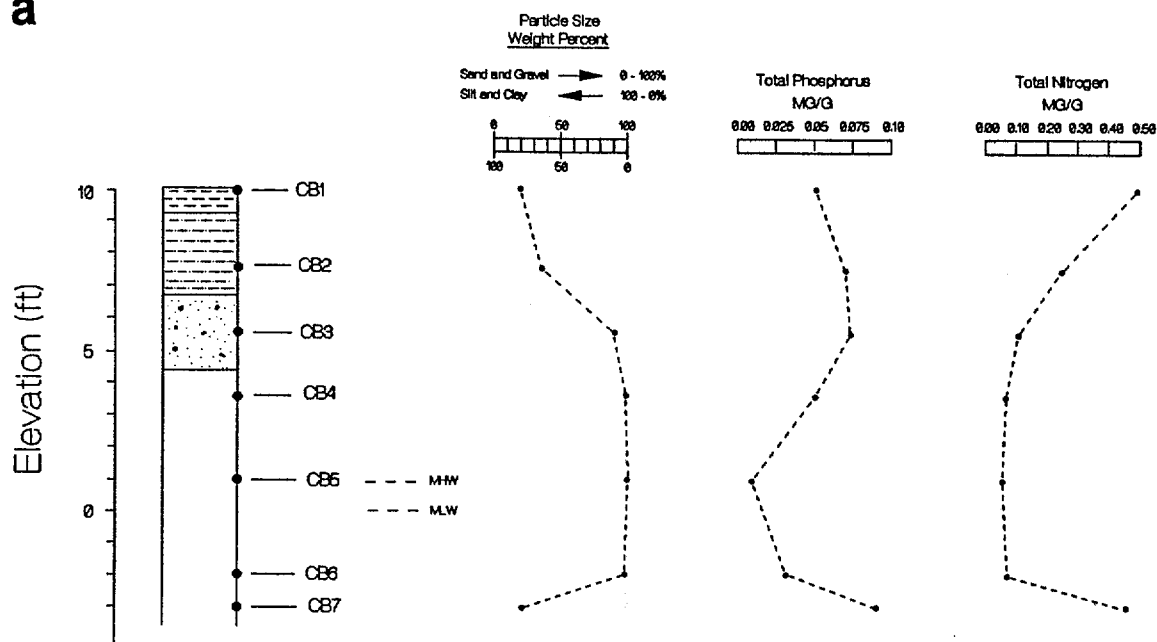


Figure 18. Grain size, total phosphorus and total nitrogen concentration: a) Nomini Cliffs and b) Great Point.

a



b

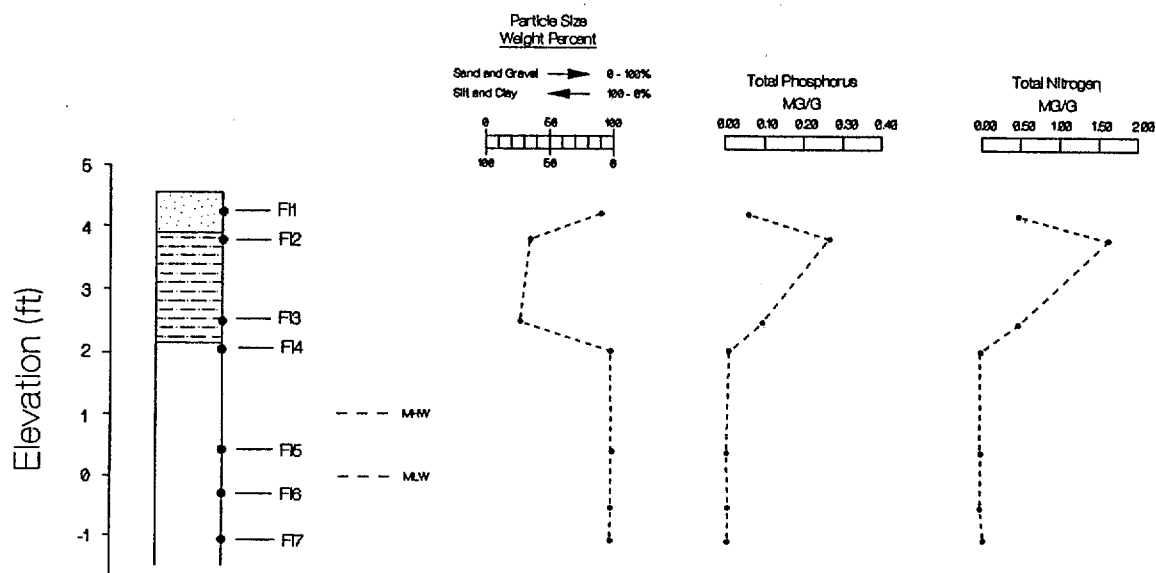


Figure 19. Grain size, total phosphorus and total nitrogen concentration: a) Chesapeake Beach and b) Fleets Island.

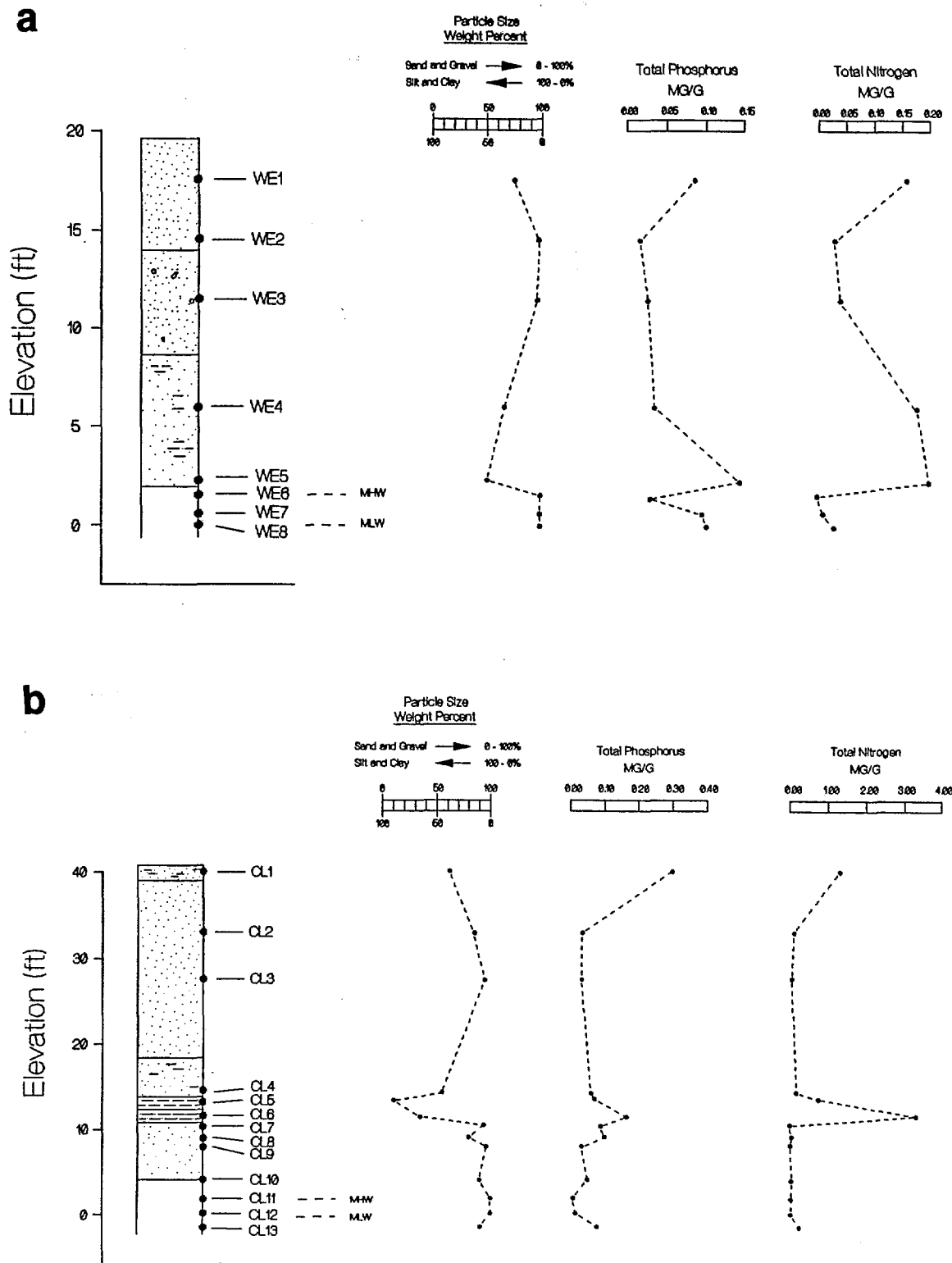


Figure 20. Grain size, total phosphorus and total nitrogen concentration: a) Wellford and b) Canoe House Landing.

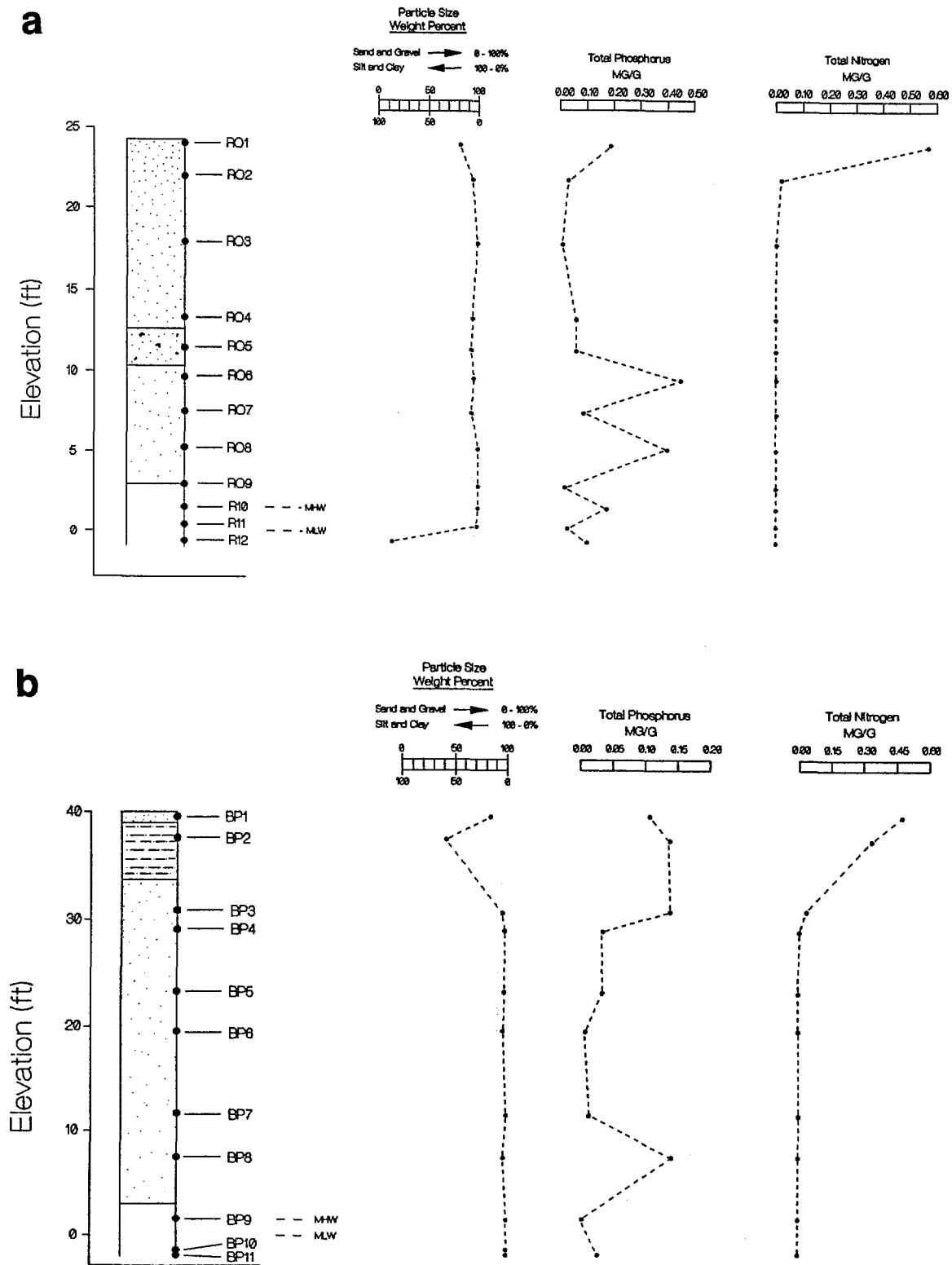


Figure 21. Grain Size, total phosphorus and total nitrogen concentration: a) Rosegill and b) Bushy Park Creek.

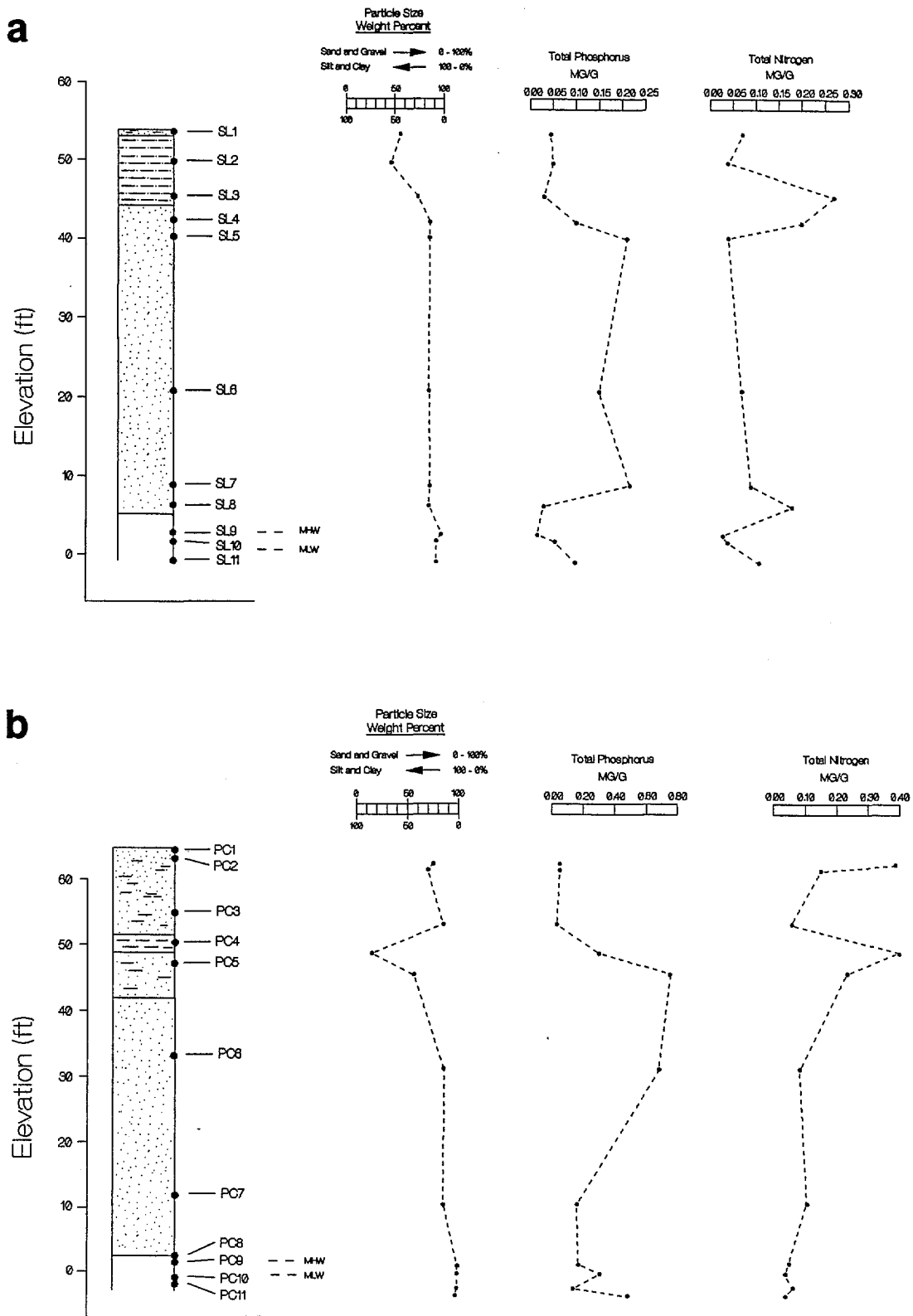
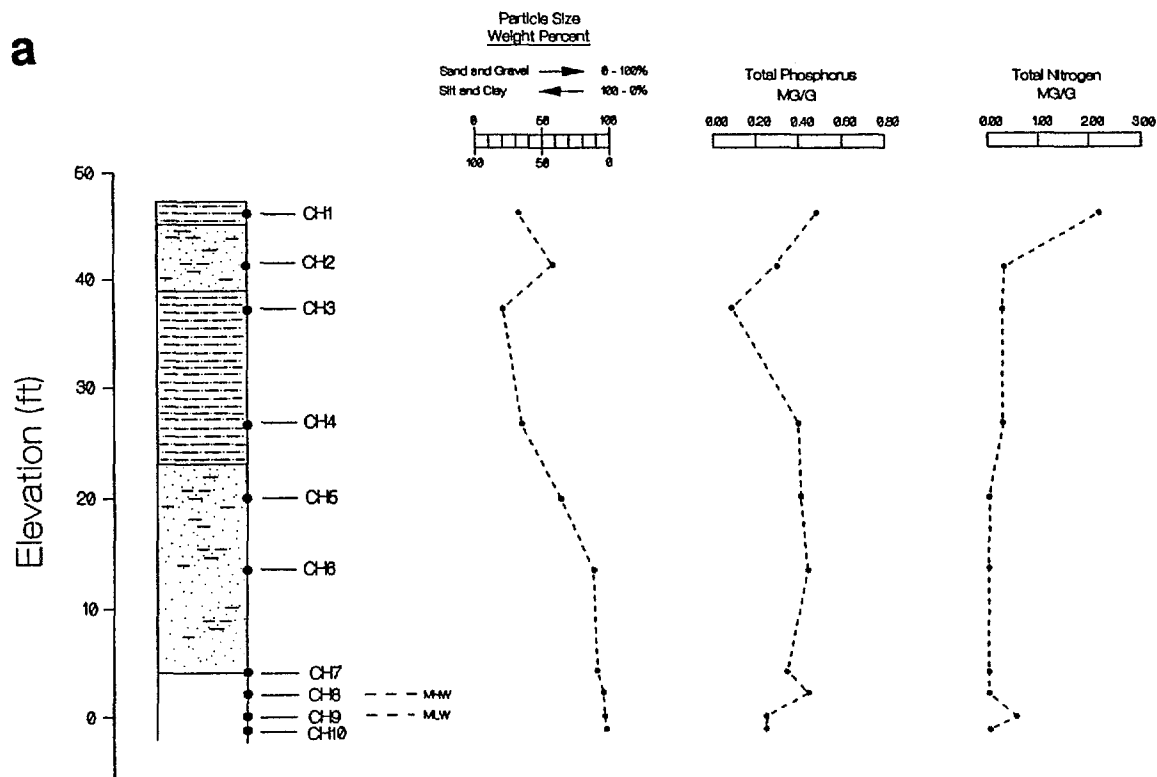


Figure 22. Grain size, total phosphorus and total nitrogen concentration: a) Sycamore Landing and b) Pipsico Camp.

a



b

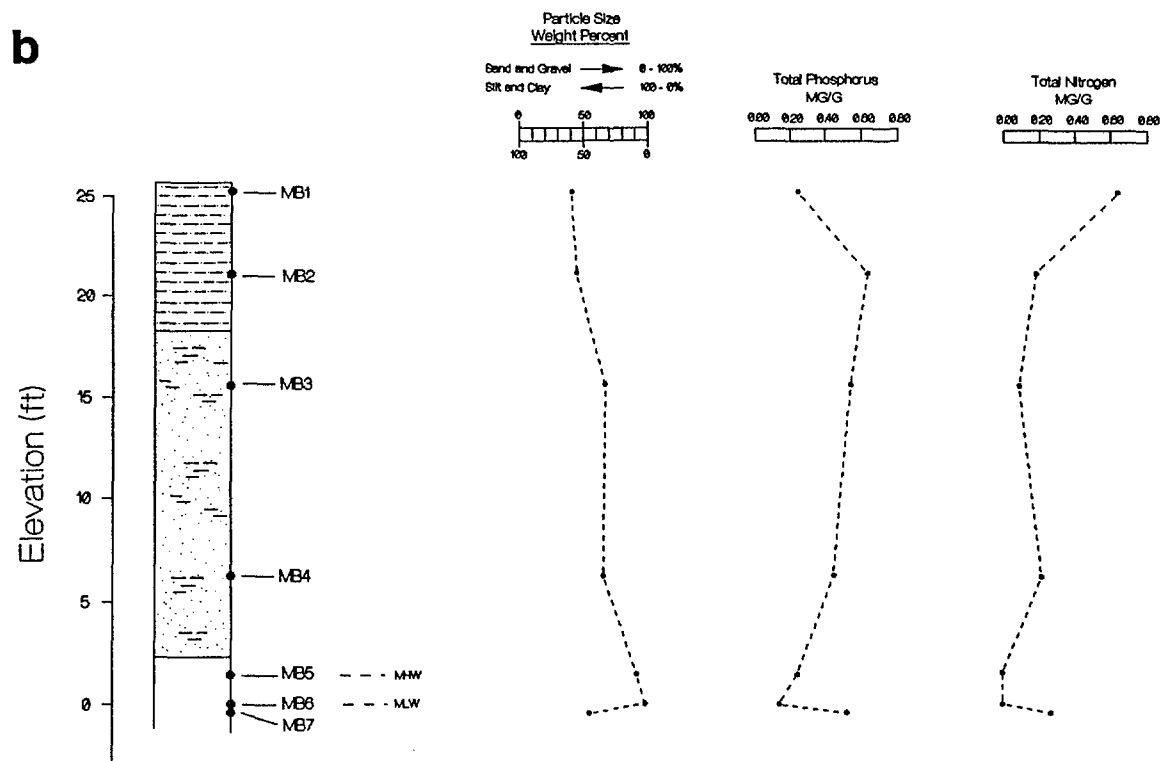
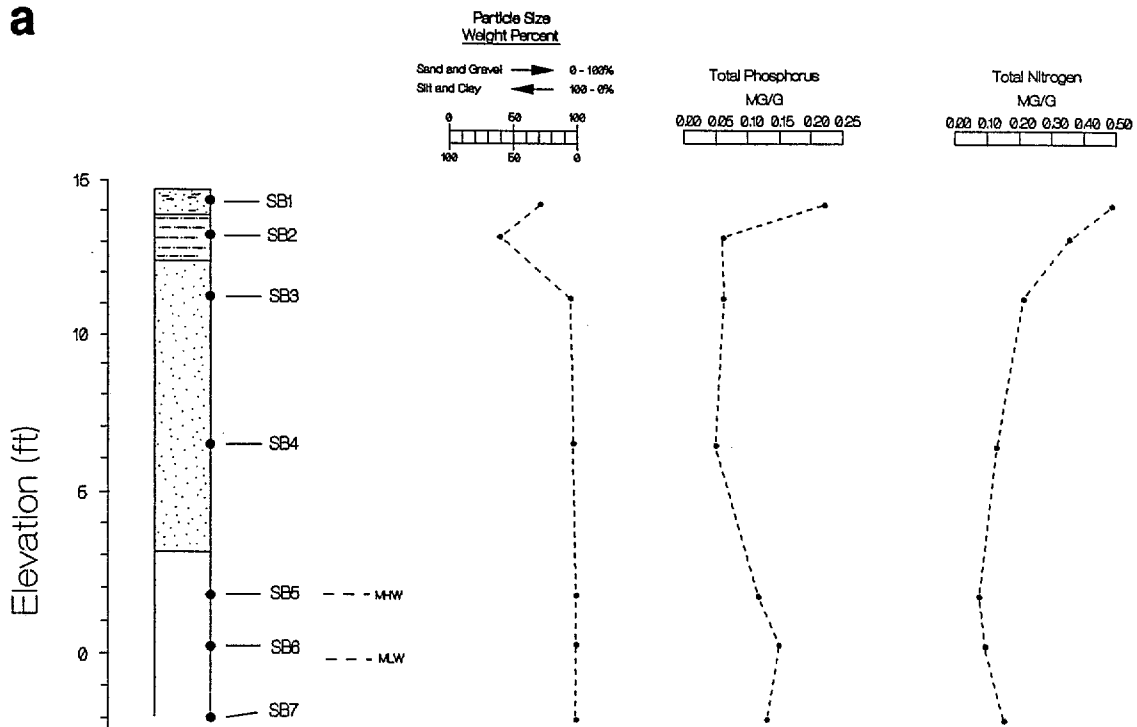


Figure 23. Grain size, total phosphorus and total nitrogen concentration: a) Chippokes State Park and b) Mogarts Beach.

a



b

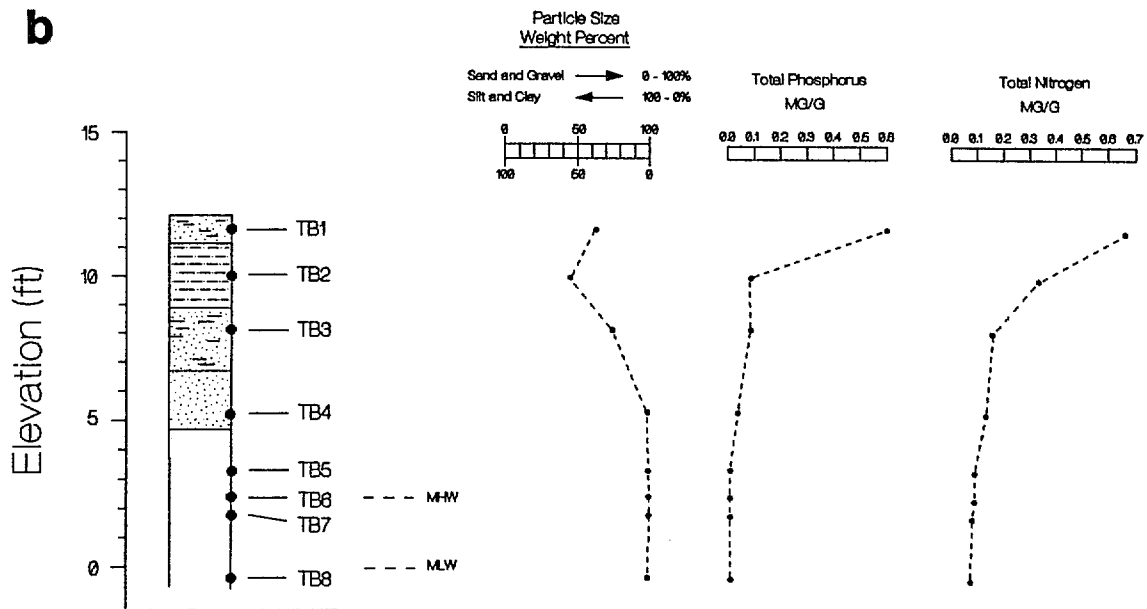


Figure 24. Grain size, total phosphorus and total nitrogen concentration: a) Silver Beach and b) Tankards Beach.

Phosphorus concentrations were more erratic than the nitrogen concentrations. There was no consistent evidence of a relationship between phosphorus concentration, grain size and bank height.

Because of the evidence of a trend in nitrogen concentrations, linear regression analysis was used to determine whether or not a significant relationship exists between grain size and the concentration of nitrogen or phosphorus. When all bank samples were included in the analysis, the regression of nitrogen with grain size had an r^2 of 0.26. No relationship between phosphorus concentration and grain size was shown. However, when the nutrient rich upper horizons (approximately 5-7 feet or the top two samples) were excluded from the analysis, the regression of nitrogen with grain size had an r^2 of 0.73. The regression of phosphorus with grain size had a low r^2 of 0.18. (The regression equations are provided in Appendix D.)

The work of Mostaghimi et al. (1989) with deep soil cores showed similar trends in nitrate nitrogen with depth. Mostaghimi et al. attributed increases ("spikes") in the nitrate nitrogen concentration at depth to decreased permeability of fine grained layers. Simpson (personal communication) noted that nitrate nitrogen is stored in soil micropores. Simpson theorized that nitrogen spikes associated with fine grained layers may also be influenced by increased micropore volume of fine textured soils.

V. DISCUSSION

Comparison of Shoreline Erosion and Upland Erosion

To address the role of tidal shoreline erosion as a contributor to nonpoint source pollution, the nutrient concentrations and loading rates calculated in this study should be compared with other nonpoint source data. Given the emphasis on agriculture as a major nonpoint source contributor (U.S. Environmental Protection Agency, 1983), one can compare the relative "importance" of nonpoint source pollution from shoreline erosion with agricultural nonpoint source pollution. As the first step in making a comparison, the nature of the processes of upland erosion and shoreline erosion must be understood.

In the upland erosion process, sediment particles and soluble nutrients from the topsoil layer are initially carried off by rainfall. The resulting runoff from agricultural fields transports the nutrients and sediments through the natural drainage system to the rivers and Bay. In the case of shoreline erosion, the entire soil profile of the exposed banks is eroded directly into the estuary. The interaction of several forces results in the loss of large volumes of soil. Wave attack is the primary agent in shoreline erosion and undermines the base of the bank. The combined forces of gravity, raindrop impact, surface water runoff and wind also act to rapidly erode steep, unstable banks. Once soil has been transported from the bank to the shore, the sediment particles are sorted and dispersed by waves and tidal currents.

To compare the relative magnitude of soil lost by upland erosion to that lost by shoreline erosion, loading rates were determined for equivalent surface areas of one acre. Documented erosion rates for the Northern Neck of Virginia were used in the following example. An acre of land may have any combination of length and width dimensions that equals 43,560 ft². In Westmoreland and Richmond Counties, the average erosion rate per acre for 3 highly erodible agricultural subwatersheds is 14 tons per year (Brown and Price, 1988).

To obtain an equivalent surface area (acre) for the shoreline case, the width dimension used equals the average shoreline erosion

rate. The length, therefore, was calculated by dividing the surface area of the acre of shoreline by the width. For example, the average shoreline erosion rate at Nomini Cliffs (Site 1) in Westmoreland County is equal to 3.5 feet per year (Byrne and Anderson, 1977). A representative acre ($43,560 \text{ ft}^2$) of shoreline therefore has a width of 3.5 feet and length of 12,446 feet or 2.4 miles (see equation and figure below).

$$\text{Length (ft)} = \frac{\text{Surface area (ft}^2\text{)}}{\text{Width (ft)}} = \frac{43,560 \text{ ft}^2}{3.5 \text{ ft}} = 12,446 \text{ ft} \quad (3)$$

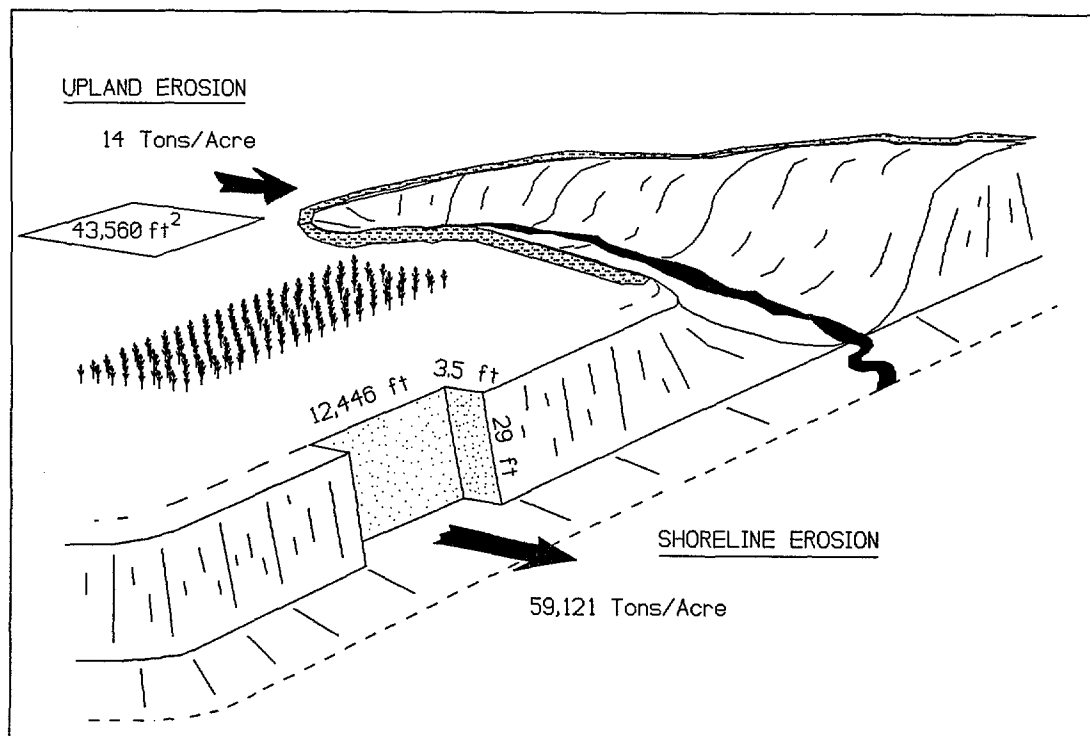


Figure 25. Illustration of upland erosion versus shoreline erosion.

The total volume of soil lost by shoreline erosion varies with the bank height at the shore. The bank height at Nomini Cliffs is 29 feet from the base to the top. The entire bank face is subjected to shoreline erosion through the undermining and sloughing process and retreats inland at the average erosion rate. The total volume of soil lost from erosion of an acre of shoreline at Nomini Cliffs in one year was found by multiplying the width (annual erosion rate) times the length of shoreline times the height of the bank.

$$\begin{aligned}\text{Volume (ft}^3\text{)} &= \text{Width (ft)} \times \text{Length (ft)} \times \text{Height (ft)} \quad (4) \\ &= 3.5 \text{ ft} \times 12,446 \text{ ft} \times 29 \text{ ft} \\ &= 1,263,269 \text{ ft}^3\end{aligned}$$

Using a soil bulk density of 1.5 g/cm^3 (93.6 lb/ft^3), the volume of eroded soil can be converted to mass (tons). Thus, erosion of one representative acre of shoreline at Nomini Cliffs annually contributes 59,121 tons of soil directly to the adjacent Potomac River waters. In contrast, erosion of a representative acre of cropland results in the loss of 14 tons of soil per year. In this example, the volume of soil lost to the estuary by shoreline erosion exceeds that lost by erosion of cropland by 3 orders of magnitude (4,223 times greater). Given the magnitude of the difference in soil loss between the two cases, the next step is to determine the nutrient inputs from each source.

Nutrient concentrations measured in this study, however, cannot be directly compared with those measured in agricultural runoff from other Chesapeake Bay area studies. Past studies of agricultural nonpoint source pollution measured soluble nutrient concentrations in runoff leaving the field. Research underway by various investigators also seeks to measure the soluble nutrient concentrations in groundwater. In the present study, residual total nitrogen and total phosphorus in the soils were measured. Mostaghimi et al. (1989) measured the remaining nitrate nitrogen in deep soil cores. As nitrogen was not measured in the same form, no comparison between their nitrate nitrogen and our total nitrogen data was made.

However, nutrient loading factors from existing studies can be compared for upland and shoreline erosion and used to calculate nutrient loading rates. Nutrient loading factors are used in the Chesapeake Bay Agricultural BMP Cost-Share program to determine the effectiveness of best management practices (BMPs). The projected nitrogen loading factor used in the Cost-Share program is 5.44 pounds per ton of soil lost (Chesapeake Executive Council, 1988). In comparison, nitrogen loading factors calculated in this study range from 0.06 to 1.77 pounds per ton of soil lost (Table 3). The Cost-Share program used phosphorus loading factors calculated for each county. For the counties studied in this report, the Cost-Share phosphorus loading factors range from 1.04 to 1.54 pounds per ton (Flagg, personal communication). Statewide, phosphorus loading factors range from 0.64 to 1.88 pounds per ton. In this shoreline erosion study, phosphorus loading factors range from 0.04 to 1.02 pounds per ton (Table 4).

The fundamental difference between the nutrient load from upland erosion versus shoreline erosion lies in the large mass of material lost through shoreline erosion and the influence of mass on calculated loading rates. Nutrient loading rates are derived by multiplying the nutrient loading factors by the mass of soil lost. Using the Cost-Share loading factors discussed above to demonstrate the contrast, approximately 76 pounds of nitrogen and 26 pounds of phosphorus would be contributed for each acre of cropland which loses 14 tons of soil per year. In contrast, the erosion of an equivalent acre of shoreline yields a nitrogen loading rate ranging from 2,153 to 66,214 pounds per acre per year with a mean rate of 19,636 pounds per acre per year. For phosphorus, the loading rate contributed by shoreline erosion ranges from 196 to 63,613 pounds per acre per year with a mean rate of 20,940 pounds per acre per year.

Another notable difference between shoreline erosion and upland erosion involves the proximity of the nutrient input to the water body. In the Cost-Share program, delivery ratios are used to pro-rate the decreasing nutrient influx from cropland erosion to the water body with increasing distance from the water body. If the land being treated with the BMP is directly adjacent to the water body, the delivery ratio is 1.

TABLE 3. Sediment Loss and Nitrogen Loading Rates

Site	Sediment Loss (tons/ft/yr)	Nitrogen		
		(lbs/ton)	(lbs/ft/yr)	(lbs/ac/yr)*
Nomini Cliffs	4.75	1.12	5.30	66,214
Great Point	1.19	0.44	0.52	2,153
Chesapeake Beach	1.64	0.49	0.79	5,794
Fleets Island	0.85	1.77	1.49	8,299
Wellford	1.97	0.25	0.49	8,918
Canoe House Ldg	10.96	0.59	6.44	43,300
Rosegill	2.45	0.06	0.14	2,789
Bushy Park Creek	5.26	0.13	0.68	9,620
Sycamore Landing	3.37	0.19	0.64	17,430
Pipsico Camp	4.53	0.25	1.14	27,419
Chippokes State Pk	2.14	0.53	1.13	44,839
Mogarts Beach	4.42	0.41	1.78	20,478
Silver Beach	3.10	0.40	1.23	9,459
Tankards Beach	2.39	0.55	1.30	8,185
Average	3.50	0.51	1.64	19,636

TABLE 4. Sediment Loss and Phosphorus Loading Rates

Site	Sediment Loss (tons/ft/yr)	Phosphorus		
		(lbs/ton)	(lbs/ft/yr)	(lbs/ac/yr)*
Nomini Cliffs	4.75	0.88	4.16	52,025
Great Point	1.19	0.04	0.04	196
Chesapeake Beach	1.64	0.13	0.22	1,537
Fleets Island	0.85	0.30	0.25	1,407
Wellford	1.97	0.12	0.22	4,281
Canoe House Ldg	10.96	0.11	1.16	8,073
Rosegill	2.45	0.23	0.55	10,691
Bushy Park Creek	5.26	0.16	0.86	11,840
Sycamore Landing	3.37	0.25	0.84	22,934
Pipsico Camp	4.53	0.58	2.59	63,613
Chippokes State Pk	2.14	0.69	1.45	58,376
Mogarts Beach	4.42	1.02	4.42	50,945
Silver Beach	3.10	0.13	0.40	3,074
Tankards Beach	2.39	0.28	0.66	4,167
Average	3.50	0.35	1.27	20,940

* Pages 42 and 43 illustrate method used to calculate tons of soil lost/shoreline acre. Tons/shoreline acre x lbs/ton of nutrient (column 2 above) = lbs/ac/yr.

As the distance between the treated land and water body increases to 1400 feet, the nutrient load to the water body is logarithmically decreased. Thus a large nutrient load originating 1400 feet inland may be greatly reduced before reaching the adjacent water body, in contrast to an initially smaller load closer to the water body that is not reduced at all before entering the water. In all shoreline erosion cases, nutrient loads are input directly into the water body.

A final, major difference in the nature of shoreline erosion versus upland erosion is that the former results in the complete loss of land and subsequent unrecoverable loss in real estate tax base. In contrast, upland erosion primarily damages the topsoil's ability to support agriculture. Shoreline land loss may also damage or destroy shore adjacent BMPs that were installed to minimize upland nonpoint source pollution.

Estimated Magnitude of NPS Nutrient Inputs from Shoreline Erosion

All sources of nonpoint source nitrogen and phosphorus inputs to the Chesapeake Bay ecosystem need to be examined to achieve the 40% nutrient reduction goal by the year 2000. The previous discussion shows that large amounts of nitrogen and phosphorus are directly released into the Bay and its major tributaries from shoreline sources (Tables 3 and 4). The next step is to estimate the relative magnitude of the nitrogen and phosphorus contribution to the Chesapeake Bay ecosystem attributable to shoreline erosion as compared with other nonpoint source inputs.

Nutrient loading estimates for Virginia's tidal waters were reported as 59.64 million pounds per year of nitrogen and 8.46 million pounds per year of phosphorus (Chesapeake Executive Council, 1988). The 1987 Chesapeake Bay Agreement targeted a 40% reduction in point source and nonpoint source nitrogen and phosphorus. Year 2000 target loads for nitrogen and phosphorus have been developed to meet this goal. Virginia's year 2000 target load for nitrogen is 35.78 million pounds per year and 5.07 million pounds per year for phosphorus (Chesapeake Executive Council, 1988). The total nutrient loads and year 2000 target loads represent the sum of the point source and "controllable" nonpoint source fractions. Although the controllable nonpoint source fraction was not specifically defined, atmospheric nutrient inputs were excluded

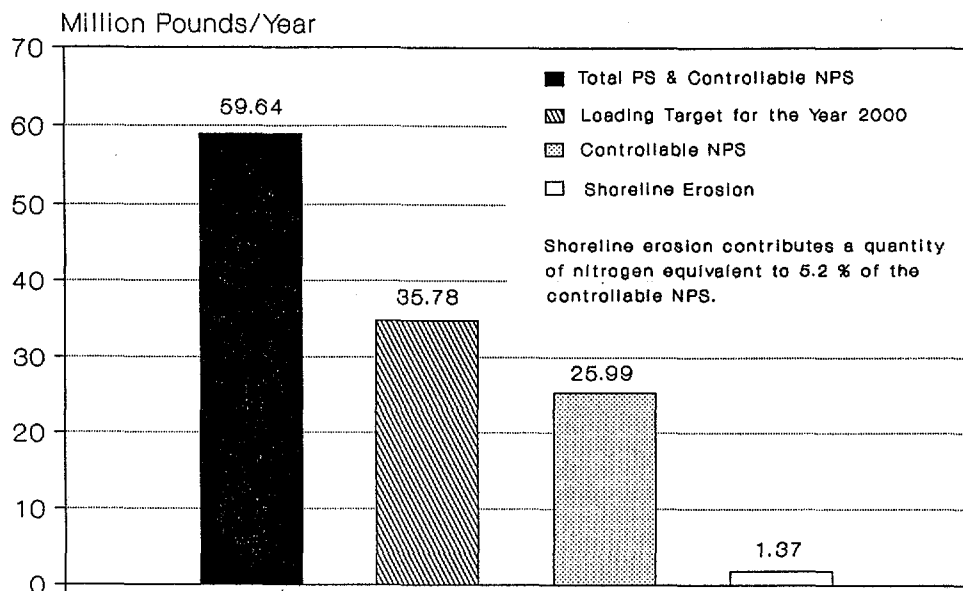
from the controllable fraction (Chesapeake Executive Council, 1988). Controllable nonpoint source nitrogen was reported to be 25.99 million pounds per year and controllable nonpoint source phosphorus as 3.98 million pounds per year (Chesapeake Executive Council, 1988).

An estimate of the total quantity of nitrogen and phosphorus entering Virginia's tidal waters from shoreline erosion can be made by multiplying the average of the nitrogen and phosphorus loading factors for the 14 sites studied (Tables 3 and 4; lbs/ton) by the annual net soil loss attributed to shoreline erosion, 2.68×10^6 tons/year. The annual net soil loss was derived by multiplying the soil bulk density by the eroded volume of soil (2.12×10^6 cubic yards/year) for approximately 1,600 miles of tidal shoreline (Byrne and Anderson, 1977). Although nutrient inputs from shoreline erosion were apparently not considered as part of controllable nonpoint source inputs, inputs attributable to shoreline erosion can be compared with controllable nonpoint source estimates to assess the relative importance of the shoreline erosion contribution. Figure 26a indicates that an estimated 1.37 million pounds per year of nitrogen is entering the Bay ecosystem through shoreline erosion. This quantity of nitrogen is equivalent to 5.2% of the controllable nonpoint source nitrogen load. Additionally, Figure 26b shows that an estimated 0.94 million pounds per year of phosphorus, equivalent to 23.6% of the controllable nonpoint source phosphorus load, is entering the Bay ecosystem.

In order to provide an equivalent reduction of 5.2% and 23.6% to the amount of controllable nitrogen and phosphorus entering Virginia's portion of the Bay through shoreline erosion, it would appear that 1,600 miles of shoreline would have to be stabilized with erosion control measures. If this were the case, funding such an effort would be expensive because of the length of shoreline involved. However, in reality, because shoreline erosion rates and the accompanying bank heights are known, the areas with the largest shoreline nutrient and sediment contributions can be identified. Since these critically eroding areas can be delineated, they represent a potentially controllable source of nitrogen, phosphorus and sediment that could be effectively eliminated from the already overloaded nutrient budget.

a

Nitrogen Loading Rates for Virginia's Portion of the Chesapeake Bay

**b**

Phosphorus Loading Rates for Virginia's Portion of the Chesapeake Bay

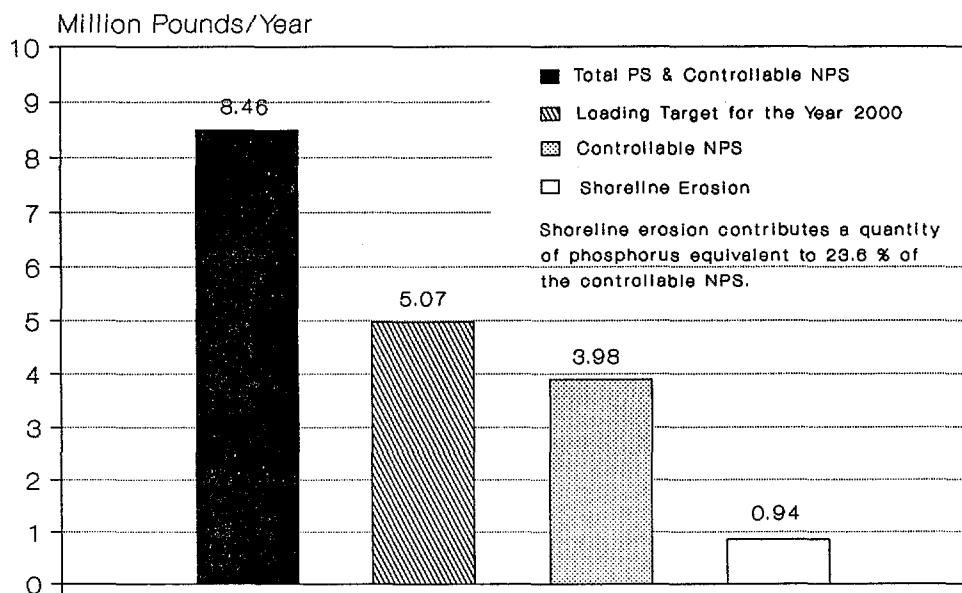


Figure 26. Loading rates for Virginia's portion of the Chesapeake Bay: a) nitrogen and b) phosphorus.

VI. RECOMMENDATIONS FOR FURTHER RESEARCH

1. Further research is needed to better determine the total magnitude of nutrient inputs from shoreline erosion and to determine the influence of the shoreline erosion contribution on the 40% nutrient reduction goal.
2. The relationship of nitrogen concentration with grain size in deep soil profiles should be investigated to better determine the cause of the nitrogen increases associated with fine grained layers.

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VIII. APPENDICES

APPENDIX A

Bank Face Samples Physical and Chemical Characteristics

Site	Sample #	Grain Size (%)				Nutrient Concentration (mg/g)			
		Gravel	Sand	Silt	Clay	TP	IP	TN	PC
1	NC1	2.0	74.0	14.1	9.9	0.09	0.009	0.90	16.35
	NC2	0.0	68.8	11.9	19.3	0.05	0.002	0.30	3.07
	NC3	0.0	97.0	0.6	2.4	0.01	0.004	0.00	0.07
	NC4	0.0	34.0	39.8	26.1	0.11	0.047	0.45	3.58
	NC5	0.0	12.7	45.4	41.8	0.56	0.100	1.11	13.80
	NC6	0.0	29.5	44.1	26.4	1.28	1.234	0.70	12.90
2	GP1	0.2	47.5	40.2	12.1	0.03	0.002	0.54	13.50
	GP2	0.0	43.1	43.5	13.3	0.01	0.000	0.20	4.93
	GP3	0.2	37.2	39.7	22.8	0.02	0.001	0.11	1.13
3	CB1	0.1	19.3	55.8	24.8	0.05	0.001	0.49	5.49
	CB2	0.2	35.3	43.4	21.2	0.07	0.004	0.25	0.98
	CB3	21.6	62.9	6.2	9.3	0.09	0.005	0.16	0.70
4	FI1	9.3	82.0	5.2	3.5	0.06	0.012	0.47	10.80
	FI2	0.1	36.0	43.4	20.4	0.27	0.174	1.65	43.50
	FI3	0.0	28.3	47.9	23.8	0.10	0.049	0.48	8.42
5	WE1	1.2	75.5	9.2	14.1	0.09	0.005	0.16	1.34
	WE2	0.9	97.1	0.3	1.7	0.02	0.002	0.03	0.18
	WE3	9.0	87.8	1.3	1.9	0.03	0.002	0.04	0.82
	WE4	1.3	65.7	20.8	12.2	0.04	0.003	0.18	1.24
	WE5	0.0	50.8	37.2	12.0	0.15	0.102	0.20	2.28
6	CL1	1.4	60.1	28.2	10.3	0.30	0.030	1.30	17.00
	CL2	0.9	85.3	2.6	11.2	0.04	0.004	0.12	0.66
	CL3	4.9	90.2	1.4	3.5	0.03	0.002	0.06	0.79
	CL4	0.2	55.4	20.6	23.8	0.08	0.002	0.17	1.57
	CL5	1.0	10.7	40.1	48.2	0.08	0.002	0.78	5.40
	CL6	0.0	35.6	18.5	45.9	0.17	0.004	3.34	88.30
	CL7	0.3	93.7	2.2	3.8	0.01	0.000	0.00	0.30
	CL8	0.0	80.4	6.1	13.5	0.10	0.001	0.11	1.28
	CL9	0.0	97.1	2.6	0.3	0.00	0.000	0.00	0.14
	CL10	1.4	88.0	4.7	5.9	0.06	0.000	0.01	0.30
7	RO1	0.0	81.4	11.6	7.0	0.19	0.030	0.57	6.82
	RO2	0.0	92.9	1.9	5.2	0.03	0.006	0.02	0.67
	RO3	0.0	98.5	0.3	1.2	0.01	0.002	0.00	0.04
	RO4	0.0	92.8	1.6	5.6	0.06	0.006	0.00	0.17
	RO5	19.8	76.6	1.5	2.1	0.06	0.011	0.00	0.11
	RO6	0.0	96.6	0.6	2.8	0.45	0.054	0.00	0.30
	RO7	5.3	88.1	2.3	4.3	0.08	0.016	0.02	0.12
	RO8	0.8	97.8	0.3	1.1	0.40	0.054	0.00	0.17

Site	Sample #	Grain Size (%)				Nutrient Concentration (mg/g)			
		Gravel	Sand	Silt	Clay	TP	IP	TN	PC
8	BP1	0.0	84.1	8.5	7.4	0.11	0.006	0.48	7.75
	BP2	0.0	41.3	26.7	31.9	0.14	0.004	0.34	2.70
	BP3	0.4	96.5	1.3	1.8	0.14	0.077	0.04	0.80
	BP4	0.1	98.4	0.3	1.2	0.03	0.017	0.00	0.11
	BP5	0.1	98.6	0.4	0.9	0.03	0.011	0.00	0.10
	BP6	0.0	97.4	0.5	2.1	0.01	0.002	0.00	0.12
	BP7	4.8	92.9	0.7	1.6	0.02	0.002	0.00	0.03
	BP8	0.0	95.7	0.6	3.7	0.11	0.009	0.00	0.15
9	SL1	0.0	56.4	31.6	12.0	0.05	0.002	0.07	1.06
	SL2	0.0	47.0	24.3	28.7	0.05	0.001	0.04	2.93
	SL3	0.0	73.6	5.7	20.7	0.03	0.001	0.27	6.21
	SL4	0.0	85.8	1.7	12.5	0.10	0.001	0.20	3.58
	SL5	8.2	76.5	3.8	11.5	0.21	0.002	0.04	0.66
	SL6	0.0	84.0	4.1	11.9	0.15	0.008	0.07	0.15
	SL7	0.0	86.1	6.5	7.4	0.22	0.030	0.09	0.23
	SL8	0.0	83.8	7.4	8.8	0.03	0.006	0.18	1.60
10	PC1	2.8	72.2	16.5	8.5	0.05	0.001	0.39	7.59
	PC2	5.0	65.3	18.0	11.7	0.05	0.001	0.15	1.66
	PC3	15.9	68.8	1.4	13.9	0.04	0.001	0.06	0.34
	PC4	0.2	14.6	40.7	44.6	0.28	0.002	0.41	1.59
	PC5	7.3	49.5	13.3	29.8	0.75	0.016	0.23	0.70
	PC6	11.4	75.9	3.2	9.5	0.69	0.121	0.08	12.70
	PC7	0.0	87.1	5.1	7.8	0.17	0.109	0.12	1.11
11	CH1	1.2	30.0	50.1	18.7	0.47	0.018	2.20	23.60
	CH2	0.0	58.6	9.4	32.0	0.31	0.002	0.33	1.77
	CH3	0.0	20.7	33.8	45.5	0.09	0.001	0.29	1.57
	CH4	0.0	34.2	25.8	39.9	0.39	0.012	0.28	1.65
	CH5	0.3	62.6	12.2	24.9	0.41	0.367	0.06	1.90
	CH6	4.1	84.6	4.0	7.3	0.44	0.259	0.07	3.90
12	MB1	0.4	41.1	24.1	34.2	0.23	0.009	0.64	7.33
	MB2	0.0	45.3	15.6	39.1	0.62	0.052	0.19	0.86
	MB3	0.6	67.9	16.4	15.1	0.55	0.020	0.09	15.70
	MB4	1.2	66.2	19.6	13.0	0.47	0.018	0.22	17.50
13	SB1	1.5	69.8	21.7	7.0	0.22	0.150	0.49	5.08
	SB2	0.2	40.5	34.0	25.3	0.06	0.003	0.35	2.02
	SB3	10.4	83.7	0.6	5.3	0.06	0.014	0.21	1.01
	SB4	0.0	97.5	0.2	2.3	0.05	0.025	0.13	0.89
14	TB1	0.0	62.6	27.4	10.0	0.60	0.600	0.66	7.83
	TB2	0.0	46.0	27.7	26.3	0.08	0.004	0.33	1.72
	TB3	0.0	74.4	10.7	14.9	0.08	0.014	0.16	0.98
	TB4	0.0	98.9	0.2	0.9	0.04	0.031	0.13	0.62

APPENDIX B

Shore and Nearshore Samples Physical and Chemical Characteristics

Site	Sample #	Grain Size (%)				Nutrient Concentration (mg/g)			
		Gravel	Sand	Silt	Clay	TP	IP	TN	PC
1	NC7	79.2	18.7	1.2	0.9	0.74	0.071	0.10	1.60
	NC8	26.4	70.3	1.7	1.6	0.46	0.232	0.13	1.83
	NC9	76.8	19.7	2.0	1.5	0.49	0.409	0.38	5.23
2	GP4	0.0	98.7	0.2	1.1	0.01	0.001	0.00	0.22
	GP5	14.5	81.8	0.9	2.8	0.04	0.011	0.09	2.27
	GP6	4.1	31.2	22.8	41.8	0.05	0.004	0.30	2.03
3	CB4	8.1	88.7	0.6	2.6	0.05	0.003	0.06	0.23
	CB5	0.0	98.5	0.3	1.2	0.05	0.001	0.07	0.18
	CB6	0.1	99.1	0.2	0.6	0.01	0.001	0.06	0.31
	CB7	18.2	80.1	0.3	1.4	0.04	0.006	0.08	0.46
	CB8	1.9	19.2	36.8	42.1	0.09	0.001	0.46	1.57
4	FI4	0.0	98.8	0.2	1.0	0.01	0.001	0.00	1.30
	FI5	32.1	67.0	0.1	0.8	0.00	0.000	0.00	0.14
	FI6	15.6	82.8	0.4	1.2	0.01	0.001	0.00	0.30
	FI7	7.6	90.8	0.3	1.3	0.01	0.002	0.05	0.26
5	WE6	0.6	98.5	0.3	0.6	0.04	0.029	0.00	0.24
	WE7	44.0	54.9	0.3	0.8	0.11	0.097	0.01	0.35
	WE8	52.9	46.3	0.2	0.6	0.11	0.033	0.03	0.47
6	CL11	0.0	99.5	0.2	0.3	0.02	0.000	0.01	0.21
	CL12	26.0	72.7	0.4	0.9	0.02	0.004	0.02	0.40
	CL13	1.9	88.2	4.1	5.8	0.08	0.001	0.25	2.07
7	RO9	0.2	98.4	0.1	1.3	0.02	0.011	0.00	0.18
	RO10	52.4	6.5	0.3	0.8	0.19	0.021	0.02	0.37
	RO11	0.0	97.8	0.4	1.8	0.04	0.016	0.02	0.27
	RO12	0.0	11.9	36.7	51.4	0.10	0.008	3.35	54.60
8	BP9	0.8	98.4	0.1	0.7	0.01	0.002	0.00	0.09
	BP10	20.0	79.2	0.0	0.8	----	0.001	0.00	0.10
	BP11	25.3	74.2	0.0	0.5	0.03	0.003	0.00	0.32
9	SL9	0.0	98.5	0.2	1.3	0.01	0.002	0.03	0.12
	SL10	0.9	93.5	1.3	4.3	0.06	0.006	0.04	0.20
	SL11	0.2	92.9	1.9	5.0	0.10	0.012	0.07	0.47
10	PC8	4.0	94.7	0.1	1.2	0.18	0.089	0.05	0.89
	PC9	0.1	98.9	0.3	0.7	0.32	0.076	0.04	1.18
	PC10	36.9	62.3	0.1	0.7	0.14	0.021	0.06	1.21
	PC11	7.9	90.2	0.2	1.7	0.50	0.010	0.04	10.40

Site	Sample #	Grain Size (%)				Nutrient Concentration (mg/g)			
		Gravel	Sand	Silt	Clay	TP	IP	TN	PC
11	CH7	29.5	61.3	2.4	6.8	0.37	0.273	0.04	0.66
	CH8	20.2	76.6	1.4	1.8	0.45	0.232	0.02	0.48
	CH9	3.0	95.6	0.2	1.2	0.26	0.201	0.64	4.36
	CH10	0.8	95.6	1.2	2.4	0.27	0.239	0.09	8.46
12	MB5	6.9	91.3	0.4	1.4	0.25	0.108	0.00	6.30
	MB6	11.1	87.4	0.3	1.2	0.16	0.009	0.02	17.80
	MB7	3.8	52.6	26.4	17.2	0.53	0.030	0.27	0.00
13	SB5	0.0	98.8	0.3	0.9	0.01	0.006	0.08	0.25
	SB6	0.1	98.6	0.3	1.0	0.02	0.002	0.10	0.29
	SB7	0.0	98.7	0.4	0.9	0.01	0.005	0.15	0.41
14	TB5	0.0	99.2	0.2	0.6	0.01	0.002	0.09	0.29
	TB6	0.0	99.3	0.1	0.6	0.01	0.003	0.09	0.30
	TB7	0.5	98.7	0.1	0.7	0.01	0.002	0.07	0.23
	TB8	1.0	97.8	0.3	0.9	0.01	0.007	0.07	0.33

APPENDIX C

Nutrient Loading Rates

Site Number/Name: 1 Nomini Cliffs (NC)

Height of Bank (ft): 29.0
Bank Retreat Rate (ft/yr): 3.5
Bank Erosion Volume (cubic feet/yr/ft): 101.5

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.0	0.03	0.09	0.003	0.03	0.04	0.90	0.031	0.29	0.43
6.0	0.21	0.05	0.010	0.10	0.15	0.30	0.062	0.59	0.88
5.0	0.17	0.01	0.002	0.02	0.03	0.00	0.000	0.00	0.00
4.0	0.14	0.11	0.015	0.14	0.21	0.45	0.062	0.59	0.88
6.5	0.22	0.56	0.126	1.18	1.76	1.11	0.249	2.35	3.50
6.5	0.22	1.27	0.285	2.69	4.00	0.70	0.157	1.48	2.20
29.0	1.00		0.441	4.16	6.19		0.561	5.30	7.89

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)
Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.881
Pounds/Ton of total nitrogen = 1.122

Site Number/Name: 2 Great Point (GP)

Site Number/Name: 2 Great Point (GP)

Height of Bank (ft): 2.4
 Bank Retreat Rate (ft/yr): 10.6
 Bank Erosion Volume (cubic feet/yr/ft): 25.4

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
0.4	0.17	0.03	0.005	0.01	0.01	0.54	0.090	0.21	0.31
1.0	0.42	0.01	0.004	0.01	0.01	0.20	0.083	0.20	0.30
1.0	0.42	0.02	0.008	0.02	0.03	0.11	0.046	0.11	0.16
2.4	1.00		0.018	0.04	0.05		0.219	0.52	0.77

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)

Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.035

Pounds/Ton of total nitrogen = 0.438

Site Number/Name: 3 Chesapeake Beach (CB)

Height of Bank (ft): 5.8

Bank Retreat Rate (ft/yr): 6.1

Bank Erosion Volume (cubic feet/yr/ft): 35.1

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.0	0.17	0.05	0.009	0.03	0.04	0.49	0.085	0.28	0.42
2.8	0.48	0.07	0.033	0.11	0.16	0.25	0.120	0.39	0.58
2.0	0.35	0.07	0.024	0.08	0.12	0.11	0.038	0.12	0.18
5.8	1.00		0.066	0.22	0.32		0.243	0.79	1.18

Total

Note:

Total phosphorus detection limit = 0.01 (mg/g)

Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.133

Pounds/Ton of total nitrogen = 0.486

Site Number/Name: 4 Fleets Island (FI)

Height of Bank (ft): 2.3
 Bank Retreat Rate (ft/yr): 7.9
 Bank Erosion Volume (cubic feet/yr/ft): 18.1

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
0.5	0.22	0.06	0.013	0.02	0.03	0.47	0.102	0.28	0.42
0.8	0.35	0.27	0.094	0.16	0.24	1.65	0.574	0.39	0.58
1.0	0.43	0.10	0.043	0.07	0.10	0.48	0.209	0.12	0.18
2.3	1.00		0.150	0.25	0.37		0.885	1.49	2.21

Total

Note:

Total phosphorus detection limit = 0.01 (mg/g)
 Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.301
 Pounds/Ton of total nitrogen = 1.770

Site Number/Name: 5 Wellford (WE)

Height of Bank (ft): 17.5
 Bank Retreat Rate (ft/yr): 2.4
 Bank Erosion Volume (cubic feet/yr/ft): 42.0

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
4.5	0.26	0.09	0.023	0.09	0.13	0.16	0.041	0.16	0.24
1.0	0.06	0.02	0.001	0.00	0.00	0.03	0.002	0.01	0.01
5.5	0.31	0.03	0.009	0.04	0.06	0.04	0.013	0.05	0.07
4.5	0.26	0.03	0.008	0.03	0.04	0.18	0.046	0.18	0.27
2.0	0.11	0.14	0.016	0.06	0.09	0.20	0.023	0.09	0.13
17.5	1.00		0.057	0.22	0.32		0.125	0.49	0.72

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)
 Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.115
 Pounds/Ton of total nitrogen = 0.249

Site Number/Name: 6 Canoe House Landing (CL)

Height of Bank (ft): 36.0
 Bank Retreat Rate (ft/yr): 6.5
 Bank Erosion Volume (cubic feet/yr/ft): 234.0

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.3	0.03	0.30	0.010	0.23	0.34	1.30	0.045	0.98	1.46
7.0	0.19	0.04	0.008	0.17	0.25	0.12	0.023	0.51	0.76
13.8	0.38	0.03	0.011	0.25	0.37	0.06	0.023	0.50	0.74
4.0	0.11	0.08	0.009	0.19	0.28	0.17	0.019	0.41	0.61
2.0	0.06	0.08	0.004	0.10	0.15	0.78	0.043	0.94	1.40
1.5	0.04	0.17	0.007	0.15	0.22	3.34	0.139	3.03	4.51
1.0	0.03	0.01	0.000	0.01	0.01	0.00	0.000	0.00	0.00
1.0	0.03	0.10	0.003	0.06	0.09	0.11	0.003	0.07	0.10
4.5	0.13	0.00	0.000	0.00	0.00	0.00	0.000	0.00	0.00
36.0	1.00		0.052	1.16	1.71		0.295	6.44	9.58

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)

Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.106

Pounds/Ton of total nitrogen = 0.592

Site Number/Name: 7 Rosegill (R0)

Height of Bank (ft): 22.8
 Bank Retreat Rate (ft/yr): 2.3
 Bank Erosion Volume (cubic feet/yr/ft): 52.3

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.0	0.04	0.19	0.008	0.04	0.06	0.57	0.025	0.12	0.18
3.0	0.13	0.03	0.004	0.02	0.03	0.02	0.003	0.01	0.01
6.0	0.26	0.01	0.003	0.01	0.01	0.00	0.000	0.00	0.00
4.0	0.18	0.06	0.011	0.05	0.07	0.00	0.000	0.00	0.00
3.0	0.13	0.06	0.008	0.04	0.06	0.00	0.000	0.00	0.00
1.8	0.08	0.50	0.038	0.19	0.28	0.00	0.000	0.00	0.00
2.0	0.09	0.08	0.007	0.03	0.04	0.02	0.002	0.01	0.01
2.0	0.09	0.40	0.035	0.17	0.25	0.00	0.000	0.00	0.00
22.8	1.00		0.114	0.55	0.80		0.029	0.14	0.20

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)
 Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.228
 Pounds/Ton of total nitrogen = 0.059

Site Number/Name: 8 Bushy Park Creek (BP)

Height of Bank (ft): 36.3
 Bank Retreat Rate (ft/yr): 3.1
 Bank Erosion Volume (cubic feet/yr/ft): 112.4

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.0	0.03	0.11	0.003	0.03	0.04	0.48	0.013	0.14	0.21
5.0	0.14	0.14	0.019	0.20	0.30	0.34	0.047	0.49	0.73
4.0	0.11	0.14	0.015	0.16	0.24	0.04	0.004	0.05	0.07
3.5	0.10	0.03	0.003	0.03	0.04	0.00	0.000	0.00	0.00
4.5	0.12	0.03	0.004	0.04	0.06	0.00	0.000	0.00	0.00
5.5	0.15	0.01	0.002	0.02	0.03	0.00	0.000	0.00	0.00
4.8	0.13	0.02	0.003	0.03	0.04	0.00	0.000	0.00	0.00
8.0	0.22	0.15	0.033	0.35	0.52	0.00	0.000	0.00	0.00
36.3	1.00		0.082	0.86	1.27		0.065	0.68	1.01

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)

Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.163

Pounds/Ton of total nitrogen = 0.129

Site Number/Name: 9 Sycamore Landing (SL)

Height of Bank (ft): 45.0
 Bank Retreat Rate (ft/yr): 1.6
 Bank Erosion Volume (cubic feet/yr/ft): 72.0

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
0.5	0.01	0.05	0.001	0.00	0.00	0.07	0.001	0.01	0.01
6.5	0.14	0.05	0.007	0.05	0.07	0.04	0.006	0.04	0.06
3.0	0.07	0.03	0.002	0.01	0.01	0.27	0.018	0.12	0.18
3.0	0.07	0.10	0.007	0.04	0.06	0.20	0.013	0.09	0.13
1.0	0.02	0.21	0.005	0.03	0.04	0.04	0.001	0.01	0.01
24.0	0.53	0.15	0.080	0.54	0.80	0.07	0.037	0.25	0.37
5.0	0.11	0.22	0.024	0.16	0.24	0.09	0.010	0.07	0.10
2.0	0.04	0.03	0.001	0.01	0.01	0.18	0.008	0.05	0.07
45.0	1.00		0.127	0.84	1.23		0.094	0.64	0.93

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)

Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.254

Pounds/Ton of total nitrogen = 0.188

Site Number/Name: 10 Pipsico Camp (PC)

Height of Bank (ft): 53.8
 Bank Retreat Rate (ft/yr): 1.8
 Bank Erosion Volume (cubic feet/yr/ft): 96.8

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
0.3	0.01	0.05	0.000	0.02	0.03	0.39	0.002	0.13	0.19
1.0	0.02	0.05	0.001	0.05	0.07	0.15	0.003	0.16	0.24
12.5	0.23	0.04	0.009	0.55	0.82	0.06	0.014	0.82	1.22
1.5	0.03	0.28	0.008	0.46	0.68	0.41	0.011	0.67	1.00
7.5	0.14	0.75	0.105	6.17	9.18	0.23	0.032	1.89	2.81
7.0	0.13	0.69	0.090	5.30	7.89	0.08	0.010	0.61	0.91
24.0	0.45	0.17	0.076	4.48	6.67	0.12	0.054	3.16	4.70
53.8	1.00		0.288	2.59	3.85		0.126	1.14	1.68

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)
 Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.577
 Pounds/Ton of total nitrogen = 0.253

Site Number/Name: 11 Chippokes State Park (CH)

Height of Bank (ft): 41.5
 Bank Retreat Rate (ft/yr): 1.1
 Bank Erosion Volume (cubic feet/yr/ft): 45.7

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.5	0.04	0.47	0.017	0.07	0.10	2.20	0.080	0.34	0.51
6.0	0.14	0.31	0.045	0.19	0.28	0.33	0.048	0.20	0.30
8.0	0.19	0.09	0.017	0.07	0.10	0.29	0.056	0.24	0.36
8.0	0.19	0.39	0.075	0.32	0.48	0.28	0.054	0.23	0.34
4.0	0.10	0.41	0.040	0.17	0.25	0.06	0.006	0.02	0.03
14.0	0.34	0.44	0.148	0.63	0.94	0.07	0.024	0.10	0.15
41.5	1.00		0.342	1.45	2.15		0.267	1.13	1.69

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)

Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.685

Pounds/Ton of total nitrogen = 0.533

Site Number/Name: 12 Mogarts Beach (MB)

Height of Bank (ft): 24.5
 Bank Retreat Rate (ft/yr): 3.8
 Bank Erosion Volume (cubic feet/yr/ft): 93.1

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.5	0.06	0.23	0.014	0.12	0.18	0.64	0.038	0.33	0.49
6.0	0.24	0.62	0.152	1.32	1.96	0.19	0.047	0.40	0.60
6.0	0.24	0.55	0.133	1.16	1.73	0.09	0.022	0.19	0.28
11.0	0.45	0.47	0.210	1.82	2.71	0.22	0.099	0.86	1.28
24.5	1.00		0.510	4.42	6.58		0.206	1.78	2.65

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)
 Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 1.019
 Pounds/Ton of total nitrogen = 0.411

Site Number/Name: 13 Silver Beach (SB)

Height of Bank (ft): 11.6
 Bank Retreat Rate (ft/yr): 5.7
 Bank Erosion Volume (cubic feet/yr/ft): 66.1

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
0.8	0.07	0.22	0.015	0.09	0.13	0.49	0.034	0.21	0.31
1.5	0.13	0.06	0.008	0.05	0.07	0.35	0.045	0.28	0.42
2.3	0.20	0.06	0.012	0.07	0.10	0.21	0.042	0.26	0.39
7.0	0.60	0.05	0.030	0.19	0.28	0.13	0.078	0.48	0.71
11.6	1.00		0.065	0.40	0.58		0.199	1.23	1.83

Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)
 Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.130
 Pounds/Ton of total nitrogen = 0.398

Site Number/Name: 14 Tankards Beach (TB)

Height of Bank (ft): 7.3
 Bank Retreat Rate (ft/yr): 7.0
 Bank Erosion Volume (cubic feet/yr/ft): 51.1

HORIZON									
Thick. (feet)	Rel. Thick.	Total Phosphorus				Total Nitrogen			
		Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr	Conc. (mg/g)	Rel. Conc.	Loading lbs/ft/yr	Rates kg/m/yr
1.0	0.14	0.60	0.082	0.39	0.58	0.66	0.090	0.43	0.64
2.3	0.32	0.08	0.025	0.12	0.18	0.33	0.104	0.49	0.73
2.0	0.27	0.08	0.022	0.10	0.15	0.16	0.044	0.21	0.31
2.0	0.27	0.04	0.011	0.05	0.07	0.13	0.036	0.17	0.25
7.3	1.00		0.140	0.66	0.98		0.274	1.30	1.93

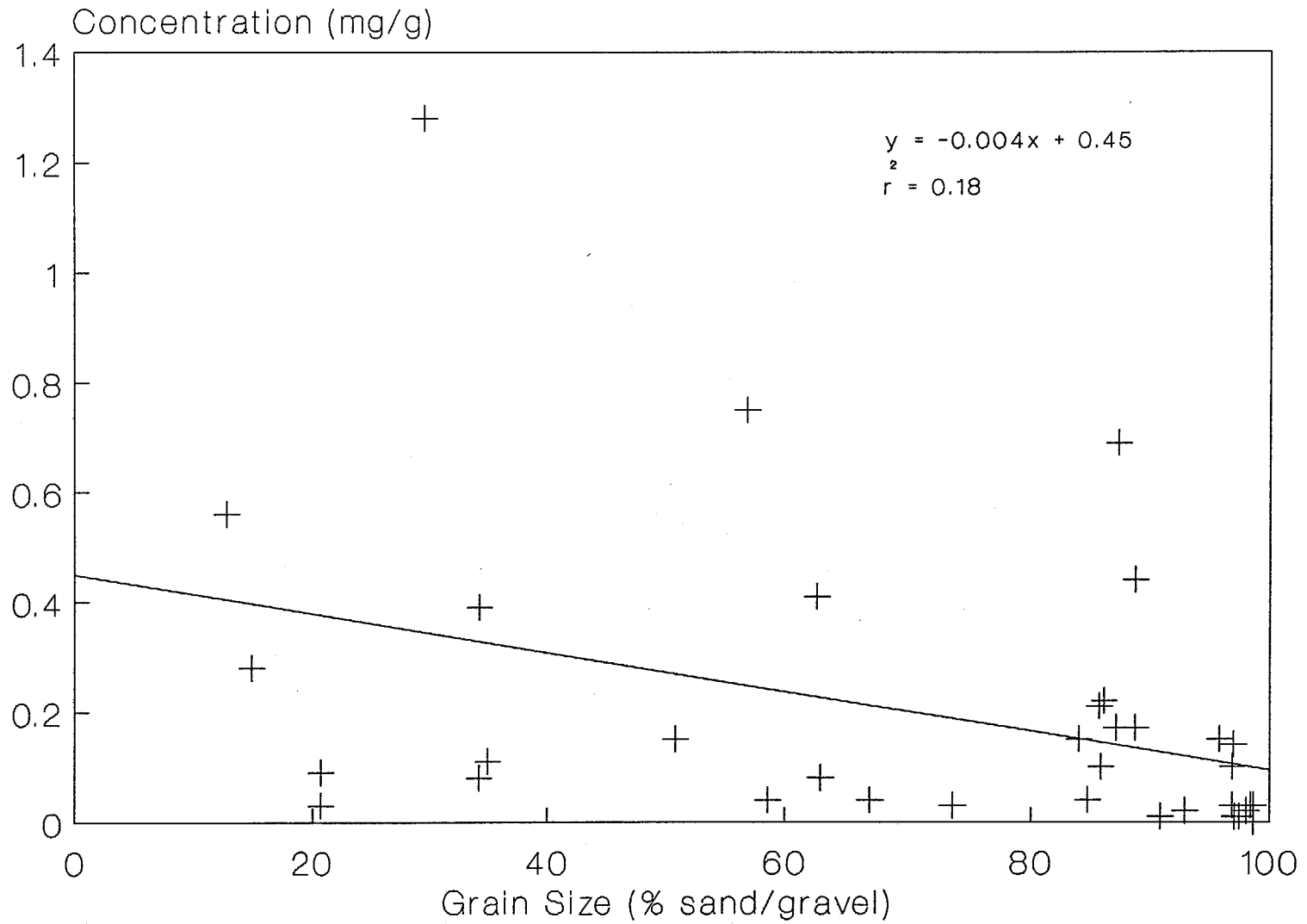
Totals

Note:

Total phosphorus detection limit = 0.01 (mg/g)
 Total nitrogen detection limit = 0.18 (mg/g)

Pounds/Ton of total phosphorus = 0.281
 Pounds/Ton of total nitrogen = 0.548

Phosphorus vs Grain Size



Nitrogen vs Grain Size

